TEXT BOOK ON
WIRELESS TELEGRAPHY

RUPERT STANLEY

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By RUPERT STANLEY, B.A., LL.D., M.I.E.E.

In Two Volumes.

With Illustrations. 8vo.

VOLUME I.

GENERAL THEORY AND PRACTICE.

VOLUME II.

VALVES AND VALVE APPARATUS.

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AND MADRAS

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VOLUME II

VALVES AND VALVE APPARATUS

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PREFACE TO THE SECOND EDITION

DURING the four years which have elapsed since the conclusion of the Great War the development of radio signalling has not been so great as might have been anticipated. Undoubtedly this is partly due to economic conditions, but the termination of the war revealed a condition of much confusion as regards the validity of patents, and this also has had a retarding effect on developments. It is now established that patent rights had been granted during the war for apparatus and uses which had previously been revealed, or were otherwise covered by the International Patent Convention. Thus the tedious delay in the establishment of broadcasting stations in Great Britain has been largely the result of disagreements between the manufacturing firms on the question of patents.

In preparing this second edition the opportunity has been taken to correct some obvious errors which had remained in the first edition; a new chapter (Chapter XVI.) has been added, in which modern types of apparatus are fully described, and such developments as those connected with high speed signalling, recorder reception, short wave signalling, and directional apparatus have been dealt with in new articles mainly in Chapter XVIII. The Armstrong method of super-audio heterodyne reception on short wave working is dealt with in Chapter XIV.

The author is much indebted to the Marconi Co. for the information placed at his disposal regarding modern types of valve apparatus, to the Radio Communication Co. for information regarding the Robinson Direction Finder, and to the Radio Corporation of America for information about their valve transmitters.

RUPERT STANLEY.

BELFAST,
October, 1922.

PREFACE TO THE FIRST EDITION

During the last four years the apparatus and practice of radio-signalling have been revolutionised by the rapid evolution of the hard vacuum valve and of valve circuits. This new era may be said to have commenced with the results obtained by Dr. Irving Langmuir, the explanation of which was clearly set forth by him, and by Edwin Armstrong, early in 1915 before the Institute of Radio Engineers.

The great world war was responsible for some remarkable developments in applied science. Not the least of these was the impetus given to radio signalling, by its multifarious applications in all branches of war activity, both offensive and defensive.

As regards developments in valves and valve apparatus the work of the French Military Service Establishment under Général Ferrié stands out pre-eminently. Colonel Ferrié, as he then was, had gathered round him a zealous band of assistants, whose scientific attainments were already very distinguished, and there is not the least doubt that their work took the lead among the Allies and held it during the war. They produced the French design of hard vacuum valve; it was marked by cheapness of construction and adaptability in action; its use by the Allies became universal, and the manufacture was copied not only by them but also by their opponents as soon as they had secured specimens.

L'Établissement Central at Paris also evolved many excellent valve circuits and pieces of apparatus which have become pioneer and are not yet excelled. In radio developments France and her Allies were well ahead of their opponents. In the United States much remarkable work has been done during these four years, especially in the development of power valves and in radio-telephony.

The author has written the present volume because it was necessary to bring his already existing Text-Book up to date. In the second place, as Wireless Experimental Officer and later as Chief Wireless Instructor with the British Expeditionary Force in France, he has had much opportunity of studying the European

development of valves and valve apparatus; it is, therefore, natural that he should wish to publish a record of the information thus gained, in the hope that it may prove interesting and acceptable.

Dr. W. H. Eccles has lately suggested that some better name could be found for the three- and four-electrode vacuum tubes used in radio signalling instead of the terms valve, pliotron, audion, etc., now commonly employed. He suggests the names triode and tetrode. The author, however, recognises that thousands of men engaged in wireless activities have become accustomed to the term "valve," and realises that any innovation, of the nature suggested, at the present time may be more troublesome than an unsatisfactory name established by custom. Also it must not be overlooked that many of the names given at present to special forms of these three- and four-electrode tubes are really trade names, and serve to distinguish the products of different manufacturing companies. For these reasons the author has been content, in this volume, to use the established term "valve" as the general name of these particular vacuum tubes used in radio signalling.

He desires to place on record his indebtedness to Général Ferrié of the French Military Service for many acts of kindness and courtesy, and for the freedom with which he explained to the author at all times what he had evolved, was evolving, or hoped to evolve in the way of valve applications. The author also wishes to express his appreciation of the valve work carried out under Général Ferrié by Prof. C. Gutton of the Faculté of Science at Nancy; a friendly intercourse with him has proved both interesting and valuable.

The thanks of the author are given to Messrs. The Marconi Co., Messrs. The General Electric Co., U.S.A., Messrs. The General Electric Co., London, The Federal Telegraph Co., U.S.A., and others, for permission to publish descriptions and illustrations of their apparatus.

RUPERT STANLEY.

BELFAST,
June, 1919.

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VALVES AND VALVE APPARATUS

CHAPTER I

ELECTRONS

ALTHOUGH the electron theory has been dealt with in Volume I. it is considered advisable to include in the present volume a brief *résumé* of the subject; by so doing it is hoped that the volume, in itself, may provide a complete study for those who already have a good knowledge of electrical science, and of the principles of Spark Telegraphy.

Under normal conditions of temperature and pressure some forms of matter exist as solids, others exist as liquids, and others as gases, but all the different kinds of matter in the material universe can be catalogued under two main headings, *i.e.* ELEMENTS and COMPOUNDS. An element, as the name implies, is a simple or elementary substance which may enter into combination with other substances, but which hitherto had not been decomposed by chemical or physical action to form new substances. There are about 83 such elementary substances known to us at present, including all the metals, such as iron, copper, gold, and zinc; certain gases such as hydrogen, oxygen, chlorine; and certain miscellaneous elements such as carbon and silicon.

If, for example, a quantity of copper unites with other things to form copper sulphate it is not possible to carry out a decomposition of the sulphate which will not yield the same quantity of copper again, neither more nor less.

The smallest portion of an element which can exist or enter into combination with something else is called an ATOM; thus a piece of copper contains a number of elementary particles or atoms, all absolutely identical, and none of them divisible into new atoms which have properties other than those of copper. All elements differ from each other in chemical and physical properties. Gold

is much heavier than hydrogen, iron has magnetic properties possessed by no other elements to the same extent, and radium has radio-active properties at ordinary temperatures shared by few other elementary substances.

A compound is a combination of two or more elements; by far the greatest number of substances with which we are familiar are compounds.

The smallest particle of a compound is called a MOLECULE, and a molecule consists of a whole number of atoms of each elementary substance present; thus water is a compound of the elements hydrogen and oxygen, and a molecule of water is made by the combination of 2 atoms of hydrogen with 1 atom of oxygen—its chemical formula is written H_2O. Similarly, a molecule of sulphuric acid is made by the combination of 2 atoms of hydrogen, 1 of sulphur, and 4 of oxygen; in chemistry this is represented by the formula—H_2SO_4.

In the same way molecules of salt, sugar, alcohol, coal gas, rubber, or any other compound, are made up of combinations of atoms of elements.

A study of all the phenomena connected with matter can therefore be based on such knowledge as we possess concerning the comparatively few fundamental elements; this involves investigations which will enable us to picture to ourselves the structure of an elementary atom. If, for example, we consider samples of iron, and copper, and hydrogen, and radium; why are they all different as regards their physical and chemical properties?

It is natural to suspect at once that there must be some difference in the structure of the atoms of different substances, but unfortunately a study of atomic structure is not easily carried out, since an atom is too small to be seen under the most powerful microscope. However the brilliant work of such scientists as Crookes, J. J. Thomson, Rutherford, H. A. Wilson, Pierre and Madame Curie has cleared up many points concerning atomic structure, and has also established the fact that electricity is an essential constituent of all forms of matter. It would take too long here to describe the experiments carried out by these and other scientists; sufficient to say that most of our present-day knowledge, concerning the structure of an atom, has been based on the phenomena observed when electric discharges have been made to pass through rarefied gases in a vacuum tube.

An electrical discharge can be passed across extremely rarefied

gas in a glass tube if two electrodes, or plates, in the tube are connected to a source of high voltage, such as the secondary terminals of a spark induction coil in action. The plate connected to the positive terminal is called the *anode*, that connected to the negative is called the *kathode*; when the voltage is applied the kathode emits rays which cause the gas in the tube to become luminescent and the glass walls to fluoresce. The rays can be deviated by a magnet, and it was early established that these rays were negatively electrified particles, projected with great velocity from the kathode. Roentgen discovered that an obstacle struck by them emits X rays; these are ether waves of length much shorter than the shortest of violet light waves.

Experiments by Milliken, Wilson, Sir J. J. Thomson, and others established the particle nature of these projectiles or rays, and showed that they were always the same whatever the nature of the electrodes used or of the gas through which they passed; they are in fact particles of what was formerly called negative electricity, but the particle is now called an ELECTRON, though in his early work Sir J. J. Thomson called it a *Corpuscle*.

By brilliant experiments the diameter of an electron, its mass, its velocity, and the charge carried by it, have been measured. Its mass is $\frac{9}{10^{28}}$ gram or is about $\frac{1}{1800}$ of that of a hydrogen atom, which is the lightest atom of all the elements; its diameter is less than $\frac{1}{3\times10^{12}}$ cm.; its velocity depends on the positive potential of the anode or plate which attracts it, and can attain a value of 50,000 kilometres per second in a high-voltage tube. Its charge corresponds to about $\frac{1}{63\times10^{17}}$ coulomb, and a substance with a surplus of electrons has properties identical with those possessed by bodies which in former times were said to be negatively electrified; the charge cannot be separated from the electron; it *is* the electron—the fundamental unit of electricity. It is probable that the mass of an electron is due to the magnetic disturbances which it causes in the ether medium; the luminescence, fluorescence, and heat caused by it in gas, and glass, and other substances are due to similar etheric disturbances. In fact all the physical properties of all forms of matter may be due to the movements of the electrons, *i.e.* units of electricity, which are a fundamental constituent of them.

The electrons are identical no matter what substance they may

issue from; thus the atoms of all elements contain electrons, and the difference between different elements is probably due to the electronic structure in the atoms. Thus gold differs from lead because an atom of gold contains a certain number of electrons arranged in a certain way, an atom of lead contains a different number of electrons arranged in a different way. Each little atom has its electrons in it, like seeds in a fruit, but there are reasons to suppose that the electrons may be moving about in the atoms, so that it is more like a little universe with its planet electrons moving around a central nucleus. By the application of electrical pressure, or voltage, one or more electrons may be torn out of an atom, as in the case of a kathodic discharge in a vacuum. Sir J. J. Thomson has shown that as many as eight electrons can be torn out of an atom of mercury. Some substances, such as radium, actinium, and uranium, emit electrons spontaneously from their atoms at ordinary temperatures and are said to be radio-active.

We do not know how many electrons there are in an atom of any substance, but it is reasonable to suppose that the number increases with the weight of an atom. Thus the atomic weight of hydrogen is 1 and its atom is supposed to contain 1 electron—the atomic weight of radium is 226 and its atom probably contains a great number of electrons.

Mendéléjeff first drew attention to what is now known as the Law of Periodicity:—If the atoms of the different elements are arranged in the order of their atomic weights it is found that atoms of similar characteristics occur periodically like octave notes on a piano. Thus lithium (atomic weight 7) has properties not shared by the substances which succeed it in the atomic scale until we come to sodium (atomic weight 23), and they disappear again until potassium (atomic weight 39) is reached. In a similar way helium (4), neon (20), and argon (39·9) have similar characteristics, as have glucinum (9·1), magnesium (24·3), and calcium (40·1); in fact so regular is this periodicity that the existence of unknown elements was shown by gaps in the series; this has led to the discovery of some of these elements, such as gallium and germanium. Spectroscopic results also demonstrate the fact that there is a definite similarity between elements which follow each other at regular intervals in the Periodic Series.

To account for this peculiar periodicity Sir J. J. Thomson considers that an atom consists of electrons, or negative charges, surrounding a central nucleus of positive charge. When the number of electrons in an atom is from 1 to 8 they are arranged

symmetrically on a circle or sphere round the central nucleus; when the number is from 9 to 16, the 9th, 10th, etc., will lie on a new circle or sphere concentric with the first. Similarly with 17 electrons a third circle or sphere would be commenced with the 17th and so on. Thus the similarity of properties of certain substances will correspond to the number of electrons on the outer circle or sphere.

The ring diameter changes with the atomic weight, so that the atomic volume diminishes as we pass through an octave, to rise again when a new ring (or octave) is started. Some doubt still exists as to the nature of the nucleus of an atom; it may be simply ether, or it may be something corresponding to what we have previously called "positive charge." On the other hand, positive charge may simply correspond to a deficit of electrons. The fact that an atom contains a positive as well as a negative charge would seem to have been proved by the experiments which P. Curie carried out with certain crystals.

Owing to the difficulty of explaining the fact that hydrogen gives two spectra, although its atom is supposed to consist of 1 electron and 1 nucleus, Sir J. J. Thomson has presented the idea that an atom may contain a third constituent whose nature is at present unknown.[1]

In the *Berichte der Deutschen Physikalischen Gesellschaft* of Dec. 30, 1917, L. Vegard contributes an interesting article on atomic structure. He assumes that in an atom of hydrogen there is 1 electron, in the next eight elements, arranged with increasing atomic weights, there are 2 electrons on the inner ring in an atom, and that in all other elements the inner ring consists of 3 electrons, the latter assumption being in accordance with the theory of Debye. Increase of atomic weight in the element series is accompanied by an increase of the number of electrons in the outer ring, and at regular periods new outer rings are started. The number of electrons on these outer ring is built up from element to element, with increase of atomic weight, until at a value of 8 or 10 a new outer ring is started.

Similar chemical properties are accounted for by the similar number of electrons on the outer rings of the atoms; thus lithium has an inner ring of 2 electrons and 1 electron on an outer ring; sodium has an inner ring of 3 electrons, a second complete ring of 7 electrons and 1 on an outer ring; potassium has rings of 3, 7,

[1] Lectures by Sir J. J. Thomson at the Royal Institution, commencing February 16, 1918.

and 8 electrons and 1 on an outer ring. The number of electrons on the outer ring may vary from 1 to 10 according to the substance.

Chemical affinity is determined by the number of electrons on the completed rings, good electrical conductivity is given by those elements which have only 1 or 2 electrons on the outer ring, whilst the more electrons there are on the outer ring the more difficult it is to separate them from the atom. A change in the number of electron rings in an atom, or the start of a new outer ring, is accompanied by the appearance of a new spectrum line.

For the first 20 elements in the atomic weight series the Table given herewith shows Vegard's theory of the atom structure; it is seen that a new ring with one electron is started at lithium, another at sodium, and another at potassium. In the remainder of the elements of increasing weight, not shown in the Table, the formation of new rings proceeds in much the same manner, the maximum number of electrons in the complete rings gradually increasing as they are formed outwards from the centre of the atom.

Element.	Atomic weight.	Electrons in			
		Inner ring.	2nd ring.	3rd ring.	4th ring.
Hydrogen	1·008	1			
Helium	3·99	2			
Lithium	6·94	2	1		
Beryllium	9·10	2	2		
Boron	11·00	2	3		
Carbon	12·00	2	4		
Nitrogen	14·01	2	5		
Oxygen	16·00	2	6		
Fluorine	19·00	2	7		
Neon	20·20	3	7		
Sodium	23·00	3	7	1	
Magnesium	24·32	3	7	2	
Aluminium	27·10	3	7	3	
Silicon	28·30	3	7	4	
Phosphorus	31·04	3	7	5	
Sulphur	32·07	3	7	6	
Chlorine	35·46	3	7	7	
Argon	37·88	3	7	8	
Potassium	39·10	3	7	8	1
Calcium	40·09	3	7	8	2

It may be thought that if an atom of an element loses one or more electrons it thereby changes into an atom of something else, and consequently by taking an electron discharge from a

substance the latter should slowly change. Up to the present the physical and chemical properties of most substances have not been found to change owing to a discharge of electrons from them, but in the case of radio-active substances it is thought that new substances of distinct individuality are produced. The radiations from thorium are supposed to bring about a very slow formation of a new substance called thorium X, but much research remains to be done in order that positive results may be established on these lines.

Now physical science teaches us that the molecules of a compound, and the atoms of an element (which may be called monatomic molecules), are in constant movement; the extent of the movement of any molecule depending on the temperature of the substance. This molecular movement is small in solids, more free in liquids, and still more free in gases; in fact it is this which distinguishes solids from liquids and gases. The pressure of a liquid or gas against the sides of the containing vessel is due to the constant bombardment of the molecules, for as they move hither and thither a definite number of them are always striking against the side of the vessel. Evaporation from the surface of a liquid is due to the fact that some of the molecules, in their movement, arrive at the surface with such a velocity that they fly off into the air, or other fluid medium, above the surface. As the temperature of the substance is increased the molecules move with greater velocity; as it is decreased the molecular movement diminishes, and at absolute zero of temperature, *i.e.* −273° C., all the molecules of a substance are at rest.

In a piece of any elementary substance it is believed that there are not only millions of atoms of that particular element, each containing a definite number of electrons, but also a great number of free electrons, and that the electrons as well as the atoms are in constant movement. Thus a piece of copper wire consists of an aggregate of atoms of copper and a number of free electrons, all in vibratory movement, the atoms being definite constellations of electrons which give the piece properties by which we distinguish it as copper. *Also it must not be overlooked that ether pervades the copper since this medium pervades everything.*

Similarly a piece of gold wire consists of a number of atoms, or constellations of electrons, and a number of free electrons, all in continual vibratory movement; but the constellations in this case consist of a different number of electrons, differently arranged to those in copper, and so gold differs from copper,

or iron, or hydrogen, or other elements in its physical characteristics.

In a metal it has been computed that there are 10^{22} free electrons per each centimetre cube of the substance, a number approximating to the number of complete atoms in the same volume.

Charged Bodies.—If, by any means, a piece of any substance is given an excess of electrons it is not in a neutral, or normal, condition; the ether which pervades it is strained, and this strain is conveyed to the ether around it so that it affects other substances in its neighbourhood. Thus if a rod of ebonite is rubbed with flannel it will attract light pieces of paper or other neutral substance near it; by the friction with the flannel it has been given an excess of electrons, and in former times was said to be thus negatively electrified, so that an excess or addition of electrons corresponds to what was formerly called negative charge.

Again, if a substance is robbed of some of its electrons by any means it is not in a normal condition; the ether in it and round it is strained, and it affects neighbouring substances. When a rod of glass is rubbed with silk, electrons leave the glass and go to the silk; the glass will then visibly attract pieces of paper or other light substances. A glass rod treated in this manner was formerly said to be positively electrified, so that on the new theory a deficit of electrons corresponds to a positive charge.

It is thus seen that properties of electric charge, or electrification, are evinced by a body when it has either an excess or deficit of electrons compared with the number in a similar normal piece of the body; this abnormal condition has set up a strain in the ether which pervades the body and the space around it, and the ether strain conveys forces to neighbouring bodies.

A charged body attracts other bodies in its neighbourhood because the electric strain set up in the ether round the charged body extends into the ether in neighbouring bodies, disturbing the normal distribution of electrons in them. The ether strain then tends to make the charged and neutral bodies move together in order that the strain may disappear. In a similar way when the strain is put on the chain of a capstan to move a weight the weight moves to remove the strain.

A body with an excess of electrons (negatively charged) will attract a body with a deficit of electrons (positively charged), because of the forces conveyed between them by the resulting strain in the ether around them. Similarly if both bodies are

either positively or negatively charged they will repel each other. In the old text-books these facts were expressed in the law: "Like charges repel each other, unlike charges attract each other."

Current of Electricity.—It has been explained that in an ordinary piece of any element, whether it be gold, copper, hydrogen gas, mercury, or any other, the atomic constellations of electrons and the free electrons are always in motion, in all directions, in the etheric medium which pervades it. The velocity of movement depends on the temperature of the piece, and the extent of the movement depends upon whether it is in a solid, liquid, or gaseous condition.

This continual movement of atoms and electrons in the piece does not lead to one portion of it having more of them than another, and the resultant strain in the ether due to these movements is zero. If, besides this movement, we can produce, by any means, a decided drift of some electrons from one portion of the piece to another that will constitute what is commonly called a current of electricity. One of the simplest means of doing this is to set up an electric strain of the ether in the piece.

Let us consider a simple case; when a rod of pure zinc is put into acidulated water the contact between them is sufficient to cause a disturbance of the normal distribution of electrons in both; the zinc gets an excess of electrons and the solution a deficit; the ether medium in and around both is electrically strained. If one end of a copper wire is now put in contact with the zinc and the other end in contact with the solution the ether which pervades the copper wire will be strained, but copper is a conductor, therefore the strain will cause a movement of electrons along the copper in order to relieve the strain. As fast as electrons flow along the copper wire to remove the strain more electrons collect on the zinc, owing to its contact with the acidulated water and the chemical action resulting therefrom, so that continual movement of electrons is kept up along that copper wire, constituting what is called a current of electricity. If a movement of electrons is only of short duration it is commonly called a discharge. The strength of the current in any substance will be directly proportional to the strain to which the ether in the substance is subjected; it will be inversely proportional to a resistance factor which depends on the nature and dimensions of the substance.

Voltage.—The amount of ether strain effect which exists between a point positively charged and one negatively charged is called the pressure, potential, or difference of potential between

the points; it is measured in units called volts. It is this strain in the ether between two points, due to the abnormal conditions represented by positive and negative charges, which causes a movement of electrons, in the form of a current or discharge, when a conducting path is available between the two points.

Resistance.—With a given electric strain exerted on the ether in any substance it is natural to expect that the resulting movement of electrons, current, or discharge, in this substance will depend upon the nature of the substance, its length, and its cross-section. For example with a given ether strain, or voltage, applied there will be a greater movement of electrons in copper than in iron or tungsten, and it will take a very great strain indeed to cause any flow of electrons in such things as mica or ebonite; thus copper is called a good *conductor*, better than tungsten; while mica, ebonite, and other substances in which movement of electrons is very difficult are called isolators, or *insulators*; across these electrons can only pass when a very great or bursting strain, measured in volts, is set up in the ether in the substance.

When a discharge or current takes place it heats the medium through which it passes to a degree depending on the resistance which the medium offers; in other words the regular drift of electrons is accompanied by a speeding up of the vibratory movement of all the atoms and electrons in the medium.

About 3000 to 4000 volts are necessary to cause a discharge of electrons across one millimetre of air; when such a discharge passes the air is heated, and we see the discharge as a spark, or succession of sparks. Electrons can discharge across a vacuum more easily than across air; air will quickly stop them on account of their extremely small size, unless there is a great difference of potential to urge them on. Thus, if it is required to pass electrons freely across a gas, the gas is generally enclosed together with two terminals or electrodes in a glass globe, and vacuum pumps applied until the gas is very thin or attenuated; until there is more or less what is commonly called a vacuum. The more completely the gas is pumped out the harder is said to be the vacuum, but it is impossible with present-day apparatus to obtain a perfect vacuum. In a suitable vacuum a discharge can be passed across a considerable space from one electrode to the other by the application of only a few thousand volts. The electrons flow from the kathode, or negative, electrode to the anode, or positive, one.

Ions.—Charges or currents may be carried not only by an

organised drift or flow of electrons, but also by portions of molecules or atoms that have broken up.

Consider the case of a liquid or gas where the molecules are freely moving about in all directions among themselves, with a velocity depending on the temperature. In their movement they will come into collision, not only with one another, but with the sides of the containing vessel, and with any electrodes mounted in it. These collisions will result in the vessel always containing a certain number of pieces of molecules which are broken; some of these pieces will have a deficit of electrons, others an excess. Thus some will carry positive charges, others negative charges, and they will therefore be attracted by the negative or positive electrodes respectively if such exist in the vessel. These carriers of electricity, of molecular or atomic size, are called *ions*, from the Greek word "ιον," meaning a wanderer. It is these ions which carry current across the solution in primary or secondary cells; their number will depend on the strength of the solution up to a certain point; it can be increased by raising the temperature of the solution, because this has the effect of increasing the molecular velocity and thus increasing the number of collisions per second. For example, if a weak solution of sulphuric acid in water is made up the solution will not only contain a number of complete molecules of sulphuric acid (H_2SO_4), all moving about in every direction, but also a number of molecules split up into parts represented by (H_2) and (SO_4). These ions will be electrified, the H_2 ion negatively, the SO_4 positively. If, now, two plates are put into the solution, one charged positively, or at a positive potential, the other at a negative potential (so that a potential strain exists in the ether between them), the negatively charged ions will be attracted to the positive plate and the positively charged ions to the negative plate. In this way a redistribution of electrons takes place tending to relieve the strain, incidentally producing a current through the liquid, and bringing the broken portions of the molecules into contact with the respective plates. The ions may react chemically on the plates.

It is noted that in the example cited one of the ions consists of two atoms of hydrogen, and it is found that the charge carried by the hydrogen ion per atom corresponds to one electron. Similar effects occur in gases; an electron flow, or current, can take place either by a general drift of electrons in one direction, or by the medium of charge-carrying ions, which are broken off portions of molecules in the gas or atoms of an elementary gas

which have lost one or more electrons. Generally both effects are present, except in the case of a very hard vacuum in which few molecules of gas are left, and therefore few ions formed by collisions; the action is then due to a flow of electrons only.

As a conclusion it may be noted that there are in the universe at least two essentials: the ether medium which pervades all space and all material substances, and electrons which are a fundamental constituent of the atoms and molecules of all substances—solid, liquid, or gas. The all-pervading medium is the more elusive of the two as far as investigation is concerned: we know such a medium must exist as we use it to convey the energy of light and heat from one place to another, but there are still unsolved many problems and experiences which are intimately connected with the existence of an all-pervading essence, the importance and sublimity of which is not yet sufficiently appreciated.

QUESTIONS ON CHAPTER I.

1. What is an electron?
2. How are molecules of compounds formed?
3. How is the difference between different substances explained on the electron theory?
4. What happens when a piece of any substance contains an excess or deficit of electrons?
5. Define electrical difference of potential and electrical resistance.
6. What is an ion?

CHAPTER II

THEORY OF THE HARD VALVE

The phenomenon of evaporation is familiar to everybody; thus if a quantity of the liquid pentane is poured out into a flat saucer it will quickly evaporate away at ordinary temperatures, and the evaporation can be hastened by heating the pentane. If water is placed in a flat saucer it will evaporate more slowly than pentane, and again the evaporation can be hastened by raising the temperature.

As pointed out in the previous chapter the molecules of a liquid are always moving about among themselves within the liquid, the velocity of movement depending on the temperature. Evaporation simply means that some molecules are always moving towards the surface at such a velocity that they escape out into the air, or atmosphere, and become diffused in it. The more the temperature is increased the greater the velocity of the molecules within the liquid, and the greater the number which will escape from the surface, so that the rate of evaporation is increased. Absolute zero of temperature, —273° C., is that temperature at which all movement of the molecules in any substance is supposed to have ceased.

When a light liquid is put on top of a heavy liquid in a glass vessel the two do not appear to mix; thus if petrol is put on top of water there appears to be a sharp dividing line between them; in reality it is easy to prove that molecules of the petrol penetrate down into the water and molecules of the water penetrate upwards into the petrol.

Similarly when a light gas is put into a vessel above one containing a heavy gas diffusion takes place; the molecules of the gases move freely about so that each of the vessels will soon contain as much of the light gas as of the heavy gas. From these and similar phenomena we conclude that the molecules in any fluid, liquid or gas, are always freely moving about within the fluid, at a

velocity determined by the temperature and the nature of the fluid, and that they can radiate or evaporate into any other fluid which may have a common surface with the first one.

Evaporation of electrons can take place from the surface of a substance in much the same way as evaporation of molecules already described. Thus, at ordinary temperatures, radium, uranium, polonium, and other so-called radio-active substances emit electrons from their surfaces; the radiation effects produced are partly caused by this stream of electrons, partly by the ejection of the resultant broken parts of atoms, and partly by the strains caused by them in the ether through which they pass.

In other cases electrons can be strongly emitted from the surface of a substance only when the latter is heated. Since an electron is very small it will be quickly stopped in air and cannot

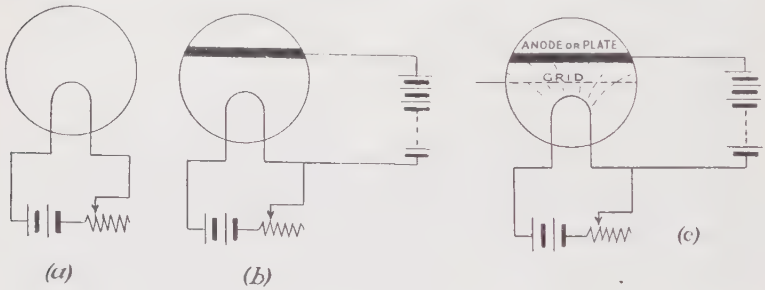


FIG. 1.

travel far, therefore to make use of such an emission of electrons it is usual to enclose the emitting surface in a vacuum.

A tungsten, platinum, or carbon filament raised to incandescent heat in a vacuum space will emit electrons, *i.e.* negative charges of electricity.

The heating can be done by an electric current from a battery, and regulated by having a resistance in series with the battery as shown in Fig. 1 (*a*). In the case of a platinum filament more electrons will be emitted if the filament is coated with some sort of lime, as first used by Wehnelt. These electrons will form a negative electric field round the filament which will repel negative charges, and therefore tend to stop further emission of electrons from the filament.

If there is introduced into the globe a plate positively charged (at a positive potential with respect to the filament), the plate will

attract the electrons, thus causing a negative flow of electricity from the filament to the plate. The electrons will be attracted along the electric strain lines which exist in the ether between the filament and the plate, caused by the difference of potential between them; a number of electrons will therefore move along this path.

The difference of potential between the plate and the filament can be kept up by a battery of cells, as shown in Fig. 1 (*b*); the chemical action between the zinc plates and the solution in the cells will keep up a redistribution or movement of electrons, so that there is a constant flow of them through the cells to the negative terminal and the hot filament attached to it, keeping them at negative potential, at the same time robbing the positive terminal and plate attached to it so that it remains at positive potential. In other words the electron current will be continuous, the flow of electrons from filament to plate being accompanied by a corresponding flow in the battery circuit, from the plate through the battery to the filament. This current will be constant in value if the temperature of the filament and the potential of the plate are kept constant, and if the vacuum of the lamp does not vary.

The number of electrons emitted from the filament depends upon its temperature and increases as the temperature is raised. Again, as the positive potential of the plate with respect to the filament is raised it will attain a value at which practically all the electrons emitted from the filament which can pass through the electric field round it, go to the plate; this condition is called "Saturation." It is easily seen that the plate potential required to give saturation depends on the temperature of the filament, *i.e.* for any given value of the heating current there is a value of voltage to use between the plate and filament which will give saturation, and there is no advantage in using any more.

It is not hard to realise that, if saturation is not attained, any variation of potential at a point in the electron path between the filament and plate will cause corresponding variation in the electron current. Such variation of potential can be made by introducing an auxiliary electrode between the filament and the plate. This electrode is generally in the form of a grid, mesh of wire, or coil of wire, through which the electrons can pass, and it is called the "Grid."

Referring to Fig. 1 (*c*), if the potential of the grid is made positive compared to the filament it will encourage and therefore

increase the flow of electrons through it to the plate, provided there is not saturation.

If the grid is kept at a negative potential, lower than that of the filament, it will tend to repel electrons and reduce the electron current from filament to plate. The repelled electrons will gather in the space between the grid and the filament, thus forming a space charge or negative field; this will still further repel the electron flow until the latter is cut off altogether, unless or until something is done to discharge the negative potential of the grid. Finally, if the grid is made alternatively positive and negative it is seen that corresponding pulses or variations in the filament-plate current will be set up. To obtain these variations satisfactorily the electron flow must be below saturation value; the potential of the plate must be arranged to suit the temperature of the filament, so that any slight change in the potential difference between them will cause a corresponding change in the electron flow.

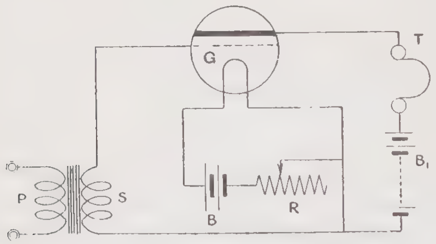


Fig. 2.

Thus, by properly designing the proportions of the various parts of such a valve, very small variations of the grid potential may cause comparatively large variations in the filament-plate current, and the advantage this arrangement possesses over other relays is that there is no inertia of moving parts; as a consequence it gives delicacy of action and absence of lag effects.

Suppose it is required to amplify weak telephonic currents, the necessary circuits would then be as shown in Fig. 2. The filament is heated by battery B, and its temperature regulated by the sliding resistance R.

The plate is kept at positive potential with respect to the filament by the battery B_1, whose voltage may be from 25 to 100, depending on the design of valve employed. The electron current flows round the circuit—filament, plate, telephone receivers (T), battery B_1—and as long as it is steady it does not cause sound in the telephones. Note that electrons are negative charges, and the electron displacement or flow round the circuit, as detailed above, is in the opposite direction to that in which we usually consider an electric current to flow. It is more usual to speak of a current as

flowing through a battery, such as B_1, from the positive terminal round the outside circuit to the negative terminal; this is because we were formerly tied too closely to the water analogy when electric displacements were not sufficiently understood. Water flows from a high level to a low level, and by analogy we considered electricity to flow from a positive potential to a negative potential. But in reality electric displacement or current may be a flow of electrons, *i.e.* negative charges, in one direction, or a flow of atoms which have lost electrons, *i.e.* positive charges, in the opposite direction, or both. Since atoms which have lost electrons are much heavier than electrons it is probable that all electric currents are due more to displacement or flow of electrons than to a displacement of the heavier positive units in the opposite direction.

The grid, G, is connected through S to the filament and therefore is normally at the same potential as one end of the filament. In series with it is the secondary S of the telephone transformer, the primary P of which takes the place ordinarily occupied by the telephone receivers.

When weak pulses of current flow in the primary they cause little pulsations of voltage to be induced in the secondary, consequently a pulsing potential effect is impressed on the grid and this causes relatively large pulsations of the electron flow, *i.e.* of the current in the plate-filament circuit and in the telephone receivers.

This is, as it were, a local current actuated by the feeble telephonic currents from the line, therefore the action is a true relay effect.

Instead of the telephone receivers we might pass the filament-plate current through the primary of a second transformer whose secondary is in the grid circuit of a second valve, thus using the magnified pulses of the first valve to give still greater pulses in the plate circuit of the second valve as shown in Fig. 3.

Again, by suitable connections one 4-volt battery can be used to heat both filaments, and one H.T. battery to serve both plate circuits. Valves connected in this manner are said to be in "cascade," and a 3-valve amplifier will make signals very loud which would otherwise be inaudible.

Before considering the use of a valve as a detector, and as an amplifier of high frequency oscillations in a wireless receiver circuit, the history and evolution of the Hard Valve will be here briefly outlined.

The discharge of electricity from incandescent metal filaments,

as already described, was investigated by Elster and Geitel during the years 1882-1889. Contributions to these investigations were made by Edison, Fleming, Sir J. J. Thomson, Richardson, and Wehnelt, the last named of whom used a lime-covered platinum filament (1904). Richardson concluded that the current from a heated metal filament was given by an equation of the form $C=a\sqrt{T}\times(\epsilon)^{-\frac{b}{T}}$, where C is the current per sq. cm. at absolute temperature T, ϵ the Napierian base and a and b constants; he also first used the term "Thermionic" for these currents. The work of investigation was carried on from 1908 to 1913 by Soddy, Fredenhagen, Pring and Parker, Pohl and Weidemann, and many

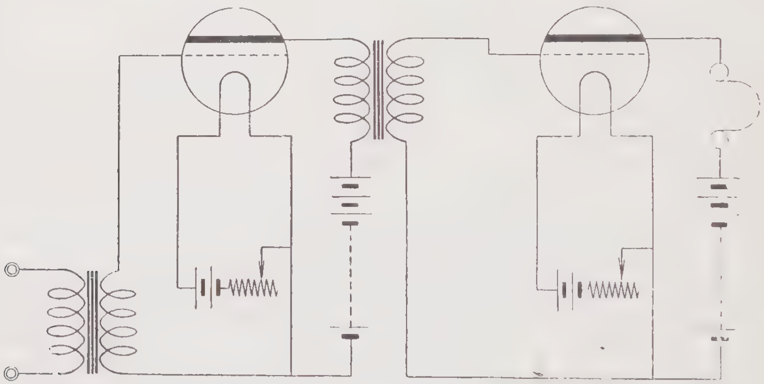


Fig. 3.

others; in every case it was concluded that electron emission could not take place unless there was some gas in the tube; and that, in fact, the emission was due to some reaction between the heated filament and the surrounding gas.

In 1913–14 Dr. Irving Langmuir conclusively proved that the presence of gas in the tube was not necessary, and that, though the strength of the electron current was very erratic in a tube containing a trace of gas, it was regular in a very hard vacuum and obeyed definite laws. Thus Fig. 4 shows the kind of result obtained by Langmuir when a filament was heated in a hard vacuum which also contained a plate kept at a high positive potential. It is seen that, when the potential of the plate is +85 volts, an increasing filament temperature gives an increasing electron current flow which is more or less in accordance with Richardson's law given

above, but at a certain temperature it fails to increase further. This is the saturation point, and the failure to increase further is due to the fact that the electrons in the space between the electrodes constitute a negative electric field, sufficiently strong to repel or stop any further increase in the flow of electrons across it, the excess electrons being turned back into the filament. An analogous action occurs in the evaporation of a liquid such as water. When

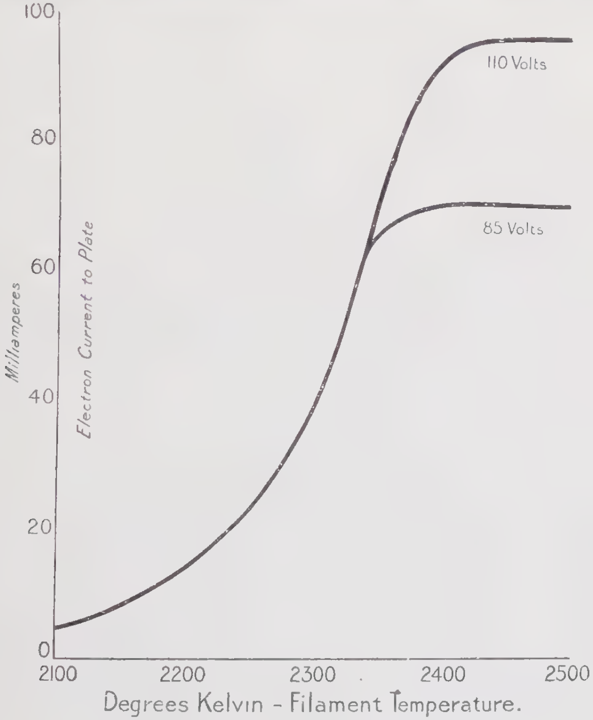


FIG. 4.

the atmosphere above a surface of water becomes very moist, that is to say, when for a given temperature it contains a certain density of aqueous vapour, as many molecules return, or are condensed back, to the surface in a given time as are emitted from it; thus evaporation appears to have ceased until something is done to decrease the amount of aqueous vapour in the atmosphere above the surface. A windy day is a good drying day, because the wind removes the damp air and allows evaporation to go on.

The same thing happens when the plate is kept at, say 110 volts positive potential; here saturation occurs at about the same time, but many more electrons are drawn to the plate owing to its higher positive potential; less are stopped by the electron field round the filament or return to the filament. In much the same way evaporation of a liquid is greater on a warm day than on a cold one; thus on a warm day the atmosphere can take up more aqueous vapour before it becomes saturated and evaporation ceases.

It may be worth while to digress here for a moment and consider the effect of leaving a trace of gas in the tube. There must not be more than a trace of gas, say a pressure of 1/100,000 mm. of mercury, because, as has already been pointed out, the electrons can only move easily through a vacuum or very attenuated gas space. Yet a slight trace of gas will make a considerable difference in the behaviour of the valve, as it provides "ions" or carriers of electric charges.

Positive ions will be produced in a tube when gas molecules collide with electrons. The effect of this collision is to split up a gas molecule into an electron and another part—the latter having lost an electron is a positively charged "ion." The positively charged ions thus formed by collision are attracted towards the filament, the freed electrons add to the effect of those given off by the filament, and are attracted with them to the plate.

Now in the first place the positive ions will neutralise the negative space charge, already discussed, and thus allow a greatly increased electron current to flow from filament to plate. For instance, if mercury vapour, at a pressure of 1/100,000 mm., is present in the tube it is possible to get as much electron current with only 25 volts on the plate as could be obtained with 200 volts on the plate were the vapour not present.

Again, it is probable that some gases do directly affect the strength of emission from certain filaments. Thus it is known that the presence of oxygen decreases, rather than increases, the emission from tungsten.

Another effect of the positive gas ions, especially with higher voltages, is the fact that, attracted by the negative field round the filament, they acquire a high velocity and when they strike the filament cause disintegration and shorten its life. Also the bombardment of the filament by the positive ions will liberate from it a distinct group of electrons; these start off with a high initial velocity and constitute what are called the Delta Rays.

The first valves designed for use on wireless circuits were all of the soft variety, that is to say the vacuum was not very hard, so that they contained a considerable number of gas molecules, and their actions were partly caused by ionic phenomena.

The pioneer valve was Fleming's valve detector; this had a hairpin filament surrounded by a cylindrical plate, but it had no grid and was simply used as a detector, *i.e.* a rectifier, because electrons would flow from filament to plate but not in the opposite direction. In 1913 the Lieben-Reisz valve appeared fitted with a grid between the filament and plate; it had a soft vacuum and was used simply as a relay of weak telephonic current pulses; about the same time De Forest produced the "Audion" valve with a grid between the filament and plate, using it in a wireless receiver circuit as a detector-relay. Round produced a similar valve which was much superior to any that preceded it; in fact it has always been the best of all soft vacuum, or gas, valves. The filament was a hairpin of platinum coated with lime, closely surrounded by a thimble grid of woven wire, outside which was the cylindrical plate. Round used his valve in conjunction with the now famous No. 16 Circuit of the Marconi Company, in which the valve was used not only as a relay for telephonic pulses but also as an amplifier of high frequency oscillations; it was not called upon to rectify, this function being mainly carried out by a crystal detector in the circuit. That a soft Round valve depends greatly for its action on the work of the positive ions is shown by the fact that when the valve hardens it becomes less sensitive. More gas molecules, and therefore ions, are produced by heating the valve to restore its lost sensitivity.

The action in a gas valve is very complex; there is normally a certain amount of ionisation, due to the constant passage of electrons from filament to plate, and the space charge is largely neutralised. When the grid assumes a positive potential the velocity and number of the electrons passing through it are increased, and more are produced in the gas. This increase of ionisation reduces the space charge and a largely increased flow of electrons through the grid to the plate ensues, so that the pure relaying action may be much greater than if no gas were present.

If a blue glow is strong, as it will be when there is too much gas, *i.e.* if the valve is too "soft," or when there is too much positive potential on the plate, it shows excessive positive ionisation; the space charge is then entirely neutralised, and although there is a

heavy electron flow from filament to plate the relaying action of the small potentials on the grid is lost.

It is perhaps necessary to remark here that the blue glow thus seen is not the flow of electrons, but is rather due to the flow of positive ions in the opposite dierction to that of the electrons.

A gas valve is not sensitive when the blue glow is too strong—in other words when the space charge is entirely neutralised. In practice control of this is carried out by putting a negative potential on the grid, using a potentiometer, grid cells, or a condenser in series with it. When a condenser is used it isolates the grid sufficiently to allow it to accumulate a negative potential from the electrons entrapped by it on their passage from the filament, and the positive ionisation of the gas prevents this negative potential from rising too high. The valve is most sensitive when worked very near the point at which the blue glow appears, but owing to the varying pressure of the gas (which in itself will vary with the temperature of the valve), to leakage of grid charge, and to the fact that the amount of positive ionisation varies with the strength of the electron current, constant adjustment is necessary to keep the valve at its sensitive point.

With a hard vacuum none of these varying effects are present and the action is very regular, as shown by the curves in Fig. 4. The hard valve made by Langmuir was called by him a Pliotron (from the Greek *pleion*, "more," and *tron*, "an instrument"). Besides pumping out the vacuum with delicate pumps every precaution is taken to ensure that no gas is left occluded in the metal plate, grid, filament or in the glass walls of the globe. The metal parts have first to be fired in a Tungsten vacuum furnace or otherwise heated to a high temperature of about 600° F., then washed in chemicals and rinsed in alcohol.

After the electrodes are mounted inside the glass globes the latter are connected to the vacuum pumps, and are placed in an oven during exhaustion so as to be kept at a temperature of 900°, rising to 1000° F. towards the end of the pumping. Ten or twelve valves can be pumped at a time, and they must be carefully watched as the temperature is near the softening point of the glass so that the globes tend to collapse when the inside pressure is reduced to that of a hard vacuum.

The vacuum is generally produced by a Gæde mercury pump, followed by a molecular or piston pump to complete the final exhaustion. During the exhaustion, and near its final stages, the plate can be bombarded by electrons by passing electric discharges

across the valve from filament to plate ; this bombardment raises its temperature and helps to shake out any remaining gas molecules occluded in the plate. The tubes leading to the vacuum pumps contain a gas absorber in the form of pentoxide of phosphorus, or liquid air traps.

Dr. Irving Langmuir described his valve before the Institute of Radio Engineers in April, 1915. A further valuable contribution was made before the same Institute in March, 1915, by Edwin Armstrong, who described circuits employed by him with the Pliotron or hard vacuum valve, and pointed out how the action differed from that of the soft vacuum valves heretofore employed.

It may be recalled that up to the time when Langmuir produced the Pliotron it had been concluded that the presence of some gas was necessary in a valve, and that the action was due partly to the " ions," and partly to chemical reactions between the gas and the hot filament.

After the war broke out the French Military Authorities at l'Establissement Centrale de Telegraphie, under the direction of Colonel Ferrié, employed what is now commonly known as the French valve ; it had a hard vacuum like the Pliotron, but the design was much simpler and, owing to the excellence of the results obtained with it, this valve became the standard one for all wireless receiver and amplifier circuits in the equipment of the Allied Armies. Since then many other hard valves have been designed, but up to the present the best European designs are those based on the French one patented by Péri and Biguet in October, 1915.

Characteristic Curve of a French Valve.—The behaviour of a valve, and the uses to which it can be put, are best studied by drawing the characteristic curve which shows the current flowing in the plate circuit for different grid potentials. In obtaining the curve the temperature of the filament and the plate potential should be kept constant ; that is to say the filament voltage and plate voltage are kept at a steady pre-determined value.

Suppose the circuits of a valve are arranged as shown in Fig. 5, with constant potentials applied to the plate and filament, and an adjustable battery B_1 of small dry cells in series with the grid, through a change-over switch S, so that the various values of positive or negative potentials can be applied to the grid. The currents in the plate and grid circuits are read on the milliammeters shown at MA ; one end of the filament is connected to earth so that the potential along the filament falls from 0 to —4 volts.

The characteristic curve of a French valve of the " S " Type

obtained in this way is shown in Fig. 6; in this case the drop of potential across the filament was 4 volts, and the potential of the plate was 50 volts higher than the zero end of the filament. Let us first study the general results obtained, as shown by the curve, and then consider their practical applications.

The curve shows that if the grid has applied to it an increasing negative potential the plate current falls off: this is to be anticipated since the grid now repels electrons, some of which return to the filament while others establish a space charge, or negative field, between the grid and the filament.

This negative field acts with the negative potential on the grid

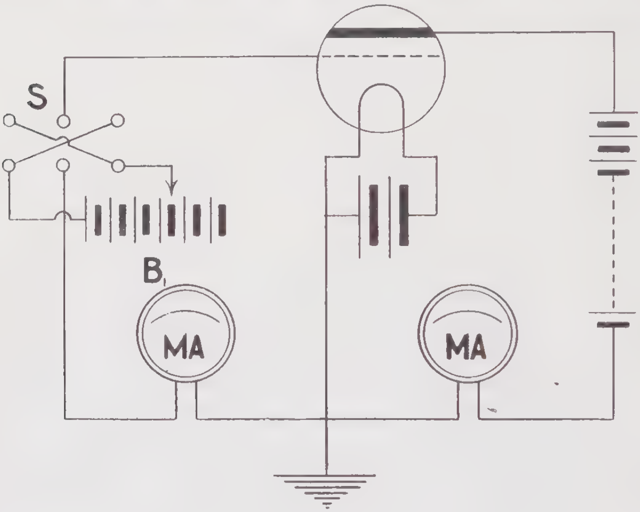


Fig. 5.

to still further reduce the plate current until, as the negative potential on the grid is increased, the electron flow is entirely stopped and the plate current is zero.

On the other hand, if the grid is at positive potential it will attract electrons; some will go to the grid itself and establish a grid current; others will pass through with increased velocity to the plate and thus the plate current is increased. Also the curve shows that as the grid potential is increased the plate current increases up to a certain point where the increase ceases; where the curve bends over and becomes horizontal. This is the point of "saturation," where an increase of grid potential will not

increase the flow of electrons to the plate, under the fixed conditions on which the valve is functioning. As will be seen later the plate current can now be increased only by increasing the filament temperature, so that it emits more electrons (as shown in Fig. 4), or by increasing the plate potential, or by increasing both.

Reference has been made to the fact that when the grid potential is raised there will be a certain value of it at which some of the electrons will go to the grid and establish a *grid current*. This will occur when the potential of the grid is higher than that of any portion of the filament; thus in Fig. 6 the grid current commences when the grid potential is about —3·8 volts. The grid current will gradually rise as the grid potential is increased until finally it also arrives at "saturation"; with modern hard valves as used on wireless receivers the grid current will always be very small compared to the plate current—it is shown on the right of Figure 6.

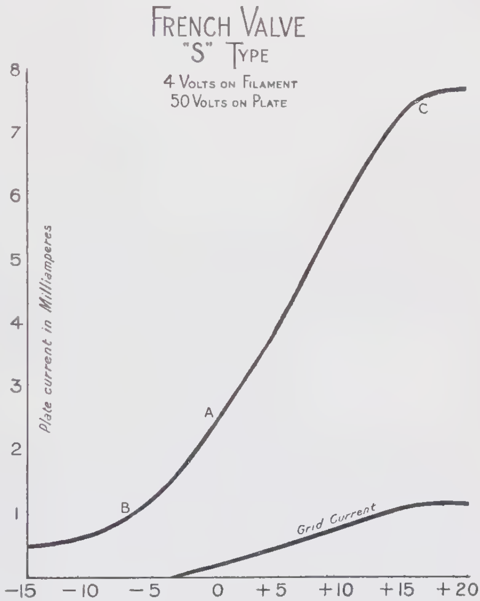


FIG. 6.

It will be seen later, when dealing with valve oscillations, that the presence of the current in the grid circuit under certain conditions of grid potential is very important.

The effect of increasing the filament temperature of a French "S" Type valve is shown in the curves of Fig. 7, the temperature of the filament being increased by simply increasing the voltage applied to it. Here it is seen that the greater the temperature of the filament the greater will be the plate current corresponding to any grid potential; a result shown in another way in Fig. 4. The effect of increasing the plate potential with constant filament temperature is shown, for a French "S" Type valve, in the curves of Fig. 8. As the plate potential is increased the curve of plate

current is shifted vertically and becomes more steep, so that for any grid potential the higher the plate voltage the greater is the plate current, and the point of zero plate current is shifted into the region of negative grid potential. For higher plate potentials than those shown in Fig. 8 the curves will be still further displaced towards the left, *but the saturation current will remain constant* depending only on the temperature of, and consequent emission of electrons from, the filament.

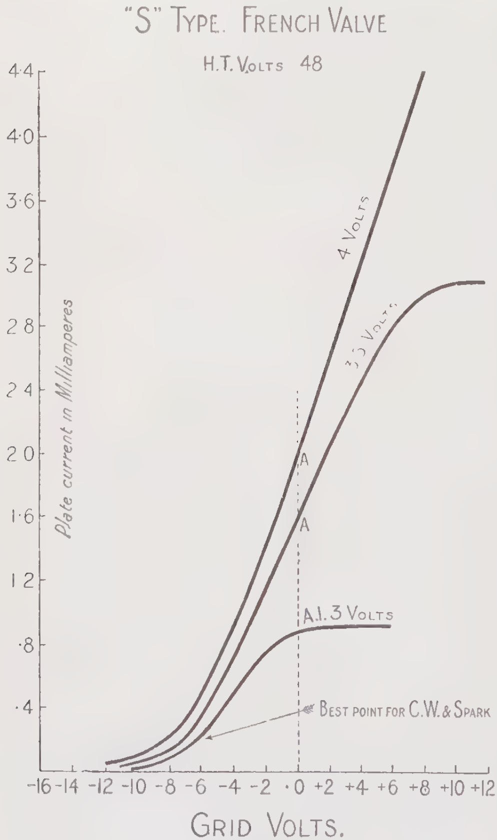


Fig. 7.

The characteristic curves of valves will be treated with greater detail in a subsequent chapter, but this preliminary short study of them is given in order that the methods of employment valves and the various uses of them may be here described in a simple manner.

Valve as a Relay.—The simplest use of a valve is as a relay or amplifier of weak telephonic currents. Referring to Fig. 6 it is seen that for such use the valve must function on the sloping part of its characteristic curve, so that the pulsations of grid potential will cause proportional pulsations of plate current, and the effects will be uniform in either direction, upwards or downwards.

Generally the initial grid potential with respect to at least one end of the filament is zero as shown in Figs. 2 and 3, where the grid is attached to, and therefore at the same potential as, one end

of the filament. The connections of the grid and filament may be made through the secondary coil of a transformer.

Thus when used as a relay the valve is functioning at about the point A on the characteristic curve of Fig. 6, corresponding to zero potential.

Similarly it can function as a relay at the corresponding points A on any of the curves shown in Figs. 7 and 8, but could not be so employed at A_1 on the 3-volt curve of Fig. 7, where a pulse of increase of grid potential above zero does not give a corresponding pulse of increase in the plate circuit current.

When the valve is used in this manner as a low frequency relay or amplifier the filament voltage and plate voltage required (in other words the characteristic curve on which it is desired to make it function) depends upon two main considerations which are opposed to each other. Firstly, the less the plate voltage, or filament voltage, or both, the less will be the steady current flowing through the plate circuit and plate circuit battery, and therefore the longer will the battery last; secondly, the higher the plate voltage, or filament voltage, or both, up to a certain point, the steeper the curve, and therefore the greater the change or pulses in the local plate circuit current made by pulses of grid potential, *i.e.* the greater the relay effect.

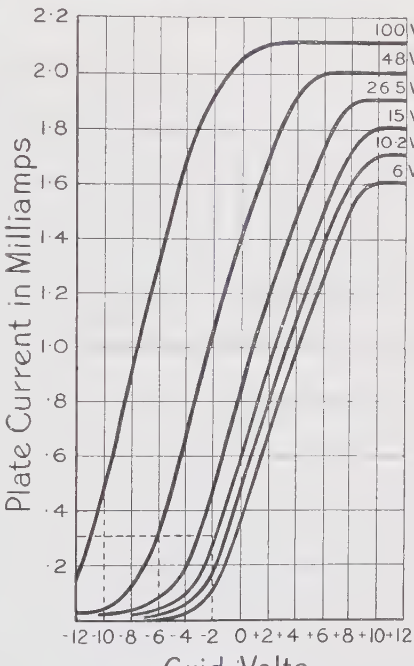


Fig. 8.

Beyond a certain point, however, relay effect does not increase with increase of plate or filament potential, because the slope of the curve does not increase in proportion to the potential, also the valve circuits are not so sensitive if the steady value of the plate current (when signals are not coming in) is too great.

It is scarcely necessary to remark that the valve will function as a relay at points on the slope of its curve other than that corresponding to zero grid potential, provided that the pulsations of grid potential caused by the signals do not cause the corresponding pulsations of plate current to reach the top or bottom flat portions of the curve. If this should happen with speech signals the speech would be distorted on reception.

Langmuir has shown that the slope of the plate current curve of a hard valve conforms very approximately to the formula :—

$$C_p = A(V_p + KV_g)^{\frac{3}{2}}$$

where A is a constant, K also a constant depending on the design of the valve, *i.e.* distance between grid and filament, size of grid mesh, hardness of vacuum, etc., and V_p and V_g are the potentials of the plate and grid respectively.

Professor Gutton of the Faculty of Nancy, who has carried out much experimental work on the French valve during the war as an assistant to Colonel Ferrié, gives the formula :—

$$C_p = aV_p + bV_g - c \quad . \quad . \quad . \quad . \quad . \quad (1)$$

for the straight-line portion of the characteristic curve. For this portion of the curve the resistance of the plate filament circuit is a constant and is given by $\frac{dV_p}{dC_p} = r_p$; in the above formula $a = \frac{dC_p}{dV_p}$ and is therefore the inverse of the plate circuit resistance. Thus we can write the formula :—

$$\begin{aligned} C_p &= \frac{1}{r_p}V_p + bV_g - c \\ \therefore C_p r_p &= V_p + KV_g - x \\ &= (V_p - x) + KV_g \quad . \quad . \quad . \quad . \quad . \quad (2) \end{aligned}$$

where K and x are constants equal to $\frac{b}{a}$ and $\frac{c}{a}$ respectively.

Now $C_p r_p$ represents the ohmic drop of volts in the plate circuit, therefore the valve acts as if there was acting in the plate circuit a potential ($V_p - x$) plus a supplementary potential KV_g due to the grid potential. From this is seen that a variation of grid potential produces a variation in the plate circuit which is K times as great, so that K *represents the potential amplifying factor of the valve.*

Again since we can write the equation :—

$$C_p = \frac{V_p - x}{r_p} + \frac{K}{r_p}V_g$$

if the grid potential changes by dV_g the plate current will change by $\frac{K}{r_p} \times dV_g$, hence $\frac{K}{r_p}$ *is the current amplifying factor of the valve.* If the plate circuit contains a resistance R external to the valve the current amplifying factor becomes $\frac{K}{r_p + R}$. For 4 volts on the filament the French valve gives the following values :—$r_p = 24{,}000$ ohms, $K = 10$, $x = 40$; or the equation is :—

$$24{,}000\ C_p = (V_p - 40) + 10V_g$$

If the filament temperature is increased the curve becomes steeper, with saturation higher and further over in the region of positive grid potential ; the resistance of the plate circuit is reduced and the current amplifying factor increased. With 5·5 volts applied to the filament and 250 volts plate potential the plate circuit resistance will fall to about 11,500 ohms, the voltage amplifying factor is about 8, and the current amplifying factor is greater than with lower filament temperatures.

The resistance of the grid circuit is very high, as can be seen by the fact that the grid circuit current is very small. Corresponding to a plate circuit resistance of 24,000 ohms the grid circuit resistance is about 40,000 ohms. With increasing negative potential on the grid the grid circuit resistance increases to infinity, which it attains at the potential where grid current becomes zero.

An increase of filament temperature increases the grid current at the same time as it increases the plate current, therefore it decreases the grid circuit resistance ; a decrease of plate potential increases the grid current therefore decreases the grid circuit resistance.

If a delicate galvanometer in the grid circuit shows that a reversed grid current is flowing when increasing negative potentials are put on the grid it is evident that this reversed current must be due to ions in the valve and that, therefore, the vacuum is not hard. This provides us with a quick method of testing the vacuum of a valve. In Nos. 3 and 4 of *L'Elettrotecnica* of 1917, G. Vallauri

deals with the Audion valve and obtains a formula for the plate current which is similar to that given above. For a point near the centre of the characteristic curve corresponding to 25 volts plate potential and $-7\cdot5$ volts grid potential he obtained the result :—

$$C_p = 16\cdot8V_p + 28V_g - 69\cdot5$$

From this we obtain—

$$\frac{C_p}{16\cdot8} = \left(V_p - \frac{69\cdot5}{16\cdot8}\right) + \frac{28}{16\cdot8}V_g$$

thus it would appear that the resistance between the plate and filament in the Audion under the above conditions was very low, the potential amplifying factor was only about 2, and the current amplifying factor was high.

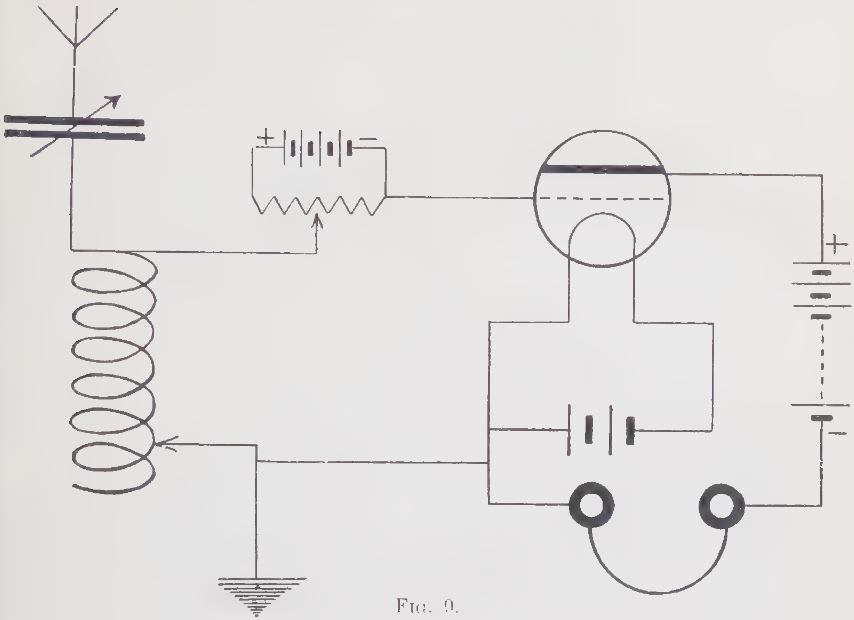
Valve as a Detector.—Referring again to Fig. 6 it will be seen that the lower portion of the characteristic curve of a valve is similar to that of a crystal detector, with a critical point at B ; rise of grid potential at this point will cause an increase of plate circuit current, but if the grid potential falls there is very little change in the plate circuit current. At this point, therefore, the valve will have rectifying properties and can be used as a detector.

Suppose the valve is connected to a simple wireless receiver circuit as shown in Fig. 9, that a fixed potential is applied to the plate, and that the filament is at constant temperature (for instance 4 volts applied to the filament) ; also that a potentiometer is employed to vary the negative potential of the grid with respect to the filament. If the grid potential is constant there will be a steady current in the plate-filament circuit and therefore through the telephones.

If pulses of grid potential occur in such a way that the *mean value of telephone current* is varied at a low frequency, then sounds will be heard in the telephone receivers ; if pulses of grid potential occur in such a way that corresponding pulses of the telephone current occur at a high frequency without changing the mean value of the current, then no sounds will be heard in the telephone receivers.

Now let us study in more detail the lower end of a characteristic curve of the valve, reproduced again on a larger scale in Fig. 10.

Under the conditions as shown in the figure suppose we



+
−
+
−

FIG. 9.

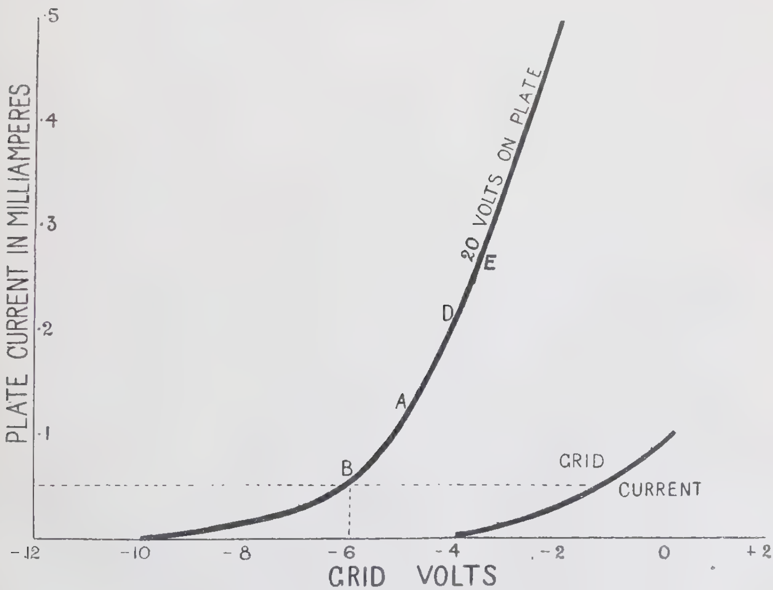


PLATE CURRENT IN MILLIAMPERES
·5
·4
·3
·2
·1
20 VOLTS ON PLATE
E
D
A
B
GRID
CURRENT
−12
−10
−8
−6
−4
−2
0
+2
GRID VOLTS

FIG. 10.

apply −6 volts to the grid, thus working the valve at the point B on its characteristic curve. It is easy to see that oscillations, or pulses of grid potential, about the value −6 volts will cause pulses in the plate current, but these will be larger for a positive pulse than for a negative one, since the curve is steeper towards the positive side; in other words, during these oscillations *the mean value of the plate current will be raised above B.* The effect of a train of oscillations in the grid potential on the plate current is shown in Fig. 11, where the pulses of increase in the mean value of the current, caused by the oscillations, are shown dotted.

Thus if the valve is connected to a receiver circuit, as in Fig. 9,

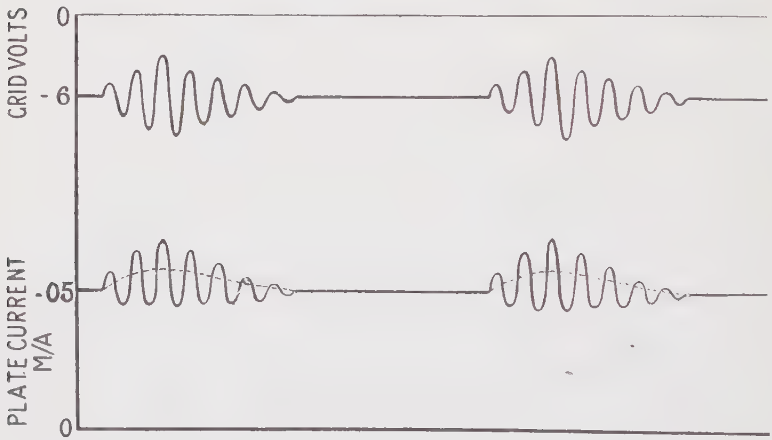


Fig. 11.

each train of oscillations will cause a slight pulse of increase in the steady current which was flowing in the plate circuit, and, therefore through the telephone receivers, so that a sound is heard in the receivers.

The valve is now acting as a detector, fairly sensitive, but probably not as sensitive as a good carborundum combination, whose characteristic curve rises more rapidly from the critical point. Note that the plate circuit steady current at this point is very small, being about 0·2 milliampere; also that there is no current to the grid. The valve has therefore the advantage that with negative potential on the grid no current flows in the grid circuit, that is to say no current energy is drawn from the oscillating

receiver circuit so that the latter is not damped. Loose coupling can therefore be employed and jamming decreased.

The pure note of the transmitting station will be heard in the receivers. The tangent to the curve of plate current at point B is not steep, so that the increase of mean current through the telephones will not be great. If the changes of plate current in the curve of Fig. 6 are noted, for two or three values of change of grid potential at the bend of the curve, it will be seen that the change of mean plate current is nearly proportional to the square of the change of grid potential; that is to say the pulses of telephone current are proportional to the squares of the amplitudes of oscillations set up in the receiver circuit, as in the case of a crystal detector.

Referring to Fig. 6 it will be seen that a similar detector action in the valve could be obtained by working the valve at the saturation point C of its characteristic curve. In this case a train of oscillations of potential set up in the grid will cause a reduction of the plate current, and therefore of the steady current in the telephones, so that a signal is heard. However, the detector properties of this part of the valve curve are only used for low values of filament volts, since otherwise it means a comparatively large current through the H.T. battery. The latter would be wasteful, and would decrease the sensitiveness of the telephones if they are connected directly in the plate circuit instead of through the intermediary of a telephone transformer. Also, even if the valve is functioning at the saturation bend of a plate current curve of low values, a grid current will probably exist, and this means that the valve has a damping effect on the oscillations.

In Fig. 7 the point A_1 on the 3-volts curve is a rectifying point, besides which this point corresponds to zero potential on the grid so that no auxiliary potential effect would be here required between grid and filament. At the same time it is seen that with only 48 volts on the plate the plate current is 0·86 ampere for the French "S" Type valve, so that this point is not so satisfactory as the lower bend, corresponding to —6 volts grid potential.

A fuller consideration of the employment of valves for rectification will be given in Chap. III.; we will conclude this one with a brief survey of the general features of hard vacuum design for amplifying relays and for wireless receiver circuits.

The filament is now invariably made of tungsten; it need not be larger than is necessary to give a small steady current in the plate circuit when no signals are arriving. Tungsten is a very

refractory material with a high volatilising temperature; it also has the property when heated of attacking any residual gases left in the globe, forming compounds with them which are volatilised and finally deposited on the glass.

As a general rule the filament in present-day valves for receiver circuits is such that it is raised to incandescence by a current of about 0·5 ampere from a 4-volt battery, though the Marconi Co. use small valves whose filament current is only about 0·3 ampere.

The grid, and the plate outside it, should surround the whole of the filament so that the electron flow takes place from all sides of the filament—as in the French valve; this is a better design than that adopted in some valves where the grid is a perforated plate on one side of the filament only, with the plate, or anode, beyond it.

The grid should be fairly close to the filament where the velocity of the emitted electrons is small; it must be remembered that the velocity of the electrons increases as they approach the positive potential plate. Dr. Eccles has shown that if ϵ represents an electron charge, and V the potential difference between the filament and the plate—then the energy represented by an electron going from filament to plate is $V\epsilon$. If its mass is m and it is supposed to start from rest and attain a final velocity at the plate of v, the kinetic energy gained by an electron when it arrives at the plate is $\frac{1}{2}mv^2$; thus $\frac{1}{2}mv^2 = V\epsilon$ or $v = \sqrt{2V \times \frac{\epsilon}{m}}$. Now $\frac{\epsilon}{m}$ is known to be $1{\cdot}77 \times 10^7$, and if V is 100 volts this gives a value for v=60,000 cms. per second; nearly 2,000 feet per second.

It is evident, therefore, that the grid should be placed close to the filament where the velocity of the electrons is still small, so that slight potential changes in the grid can appreciably affect their velocity; either accelerating their velocity out of the negative field around the filament, or repelling them back to the filament before they have got up much speed, according to the potential of the grid.

If the grid mesh is too coarse it will not have sensitive control of the electron flow, and it will require to have considerable negative potential applied to it if the valve is to function near the bottom bend of a characteristic curve, where it has rectifying properties and the plate circuit currents are small. On the other hand if the grid has too fine a mesh, a relatively small negative potential on it will cut off the plate current altogether, and the bend in the characteristic curve of the valve under suitable working conditions

may now occur in the region of positive grid potential. A fairly coarse mesh of fine wire is best for ordinary practice.

The plate is usually made of nickel ; it should be thin so that occluded gases are easily got out of it during the vacuum-producing process. For this reason the plate might be made of thin wire instead of sheet metal. It must be large enough to deal with the current passing through it, otherwise it would heat up ; thus if we apply, say, 400 volts in the plate circuit of Fig. 5, a current of 40–50 milliamperes will flow in it and would soon make the plate of the valve white hot, unless the energy could be transferred from the circuit to another one, as is done when a valve is employed for C.W. transmission.

If the plate is too far from the filament the apparent resistance across the valve is high, and the voltage drop correspondingly high ; that is to say a high plate voltage is required and the valve is not efficient. On the other hand if the plate is too close to the grid and filament its attraction for the electrons will be so strong that the valve will not be sensitive to small changes of grid potential. This mistake was made in a German copy of the French valve.

For reception the plate potential must not be higher than that required to ensure a steady flow of electrons from the filament, a flow which will readily respond to slight fluctuations of grid potential. It must be remembered that this flow acts as a current through the plate circuit battery, and the smaller it is the longer the battery will last.

These points in design will be better appreciated when the characteristics of different valves are discussed in a subsequent chapter.

QUESTIONS ON CHAPTER II.

1. What is meant by plate current saturation ? How does it vary with (*a*) plate potential, (*b*) filament temperature ?
2. Explain shortly how a valve can act as a relay for pulses of current at telephonic frequency.
3. How are the characteristics of a valve determined ?
4. How is the current amplifying factor of a valve obtained ?
5. Explain the action of a valve when used as a detector. How does the use of a valve as a detector differ from its uses as a relay and as an amplifier ?
6. Write a short note on the effects of grid and plate distances from the filament of a valve.

CHAPTER III

VALVE DETECTORS AND DETECTOR-RELAYS

In the previous chapter it has been pointed out that the plate current curve of a hard valve is of such a shape that the valve has got rectifying properties. When functioning as a detector at the lower bend of the curve the grid potential in the general case is negative compared with the filament and the grid current is zero; the grid circuit has infinite resistance and hence the valve abstracts no energy from the oscillating circuit to which it is connected, the necessary pulses of telephone current coming from the plate circuit battery. *Thus a valve employed in this way as a detector has very little damping effect on the oscillating circuit*, therefore tuning will be sharp, and loose coupling to the aerial circuit can be employed so that jamming by interference is reduced.

The damping effects of the valve are not entirely zero, for there is a small capacity effect between the grid and the other electrodes which allows some oscillating energy to pass: on account of this the valve may not be as good a detector as a good crystal on short waves or high frequencies.

Before discussing further the methods of using a hard valve for rectification it may be interesting to briefly consider some of the earlier types of valves which were used on wireless receiver circuits.

Fleming Valve. The first valve detector was patented by Dr. J. A. Fleming in 1904; it had no grid, and simply made use of the unilateral conductivity effect between a heated filament and a plate enclosed together in a vacuum. At that time it was considered so reliable and robust compared to crystal detectors that it was largely adopted on wireless installations by the Marconi Company.

The detector consisted of a small electric lamp with a single hairpin filament of tungsten or carbon, surrounded by a cylinder of sheet or gauze copper, or nickel, which was attached to a third terminal on the lamp.

The filament was heated to incandescence by means of a battery, of from 4 to 12 volts depending on the size of the valve, in series with a regulating resistance. The negative side of the filament was connected in series with a potentiometer voltage and telephone receivers to one side of the wireless receiver circuit, the copper plate or anode to the other side of the circuit.

The valve had a soft vacuum and was what we would now call a "gas valve"; its sensitiveness to signals was not so good as that of a good crystal combination, but the sensitiveness was not impaired by strong signals and atmospherics.

Fig. 12 shows a Fleming Valve as supplied by the Marconi Company; also its connections to a receiving circuit.

Fleming was the first to use the unilateral conductivity effects

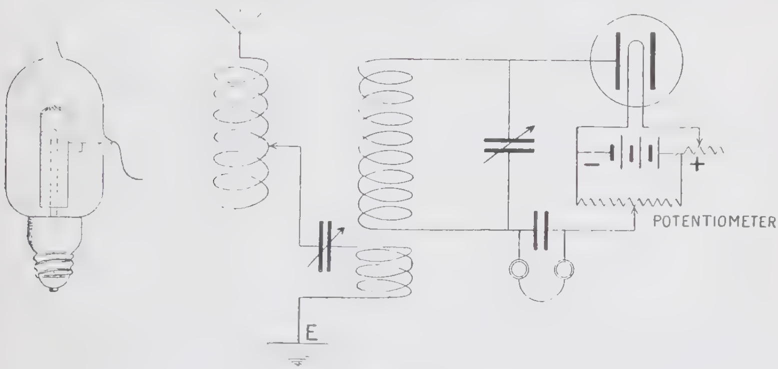


Fig. 12.

of an electron discharge, from a heated filament to a plate at a higher potential than the filament, but he made no attempt to use a third electrode which is required for relaying effects, and rectifies by space charge effects.

Lieben-Reisz Valve.—The use of a grid between the plate and filament seems to have been first applied commercially by Lieben and Reisz in their valve relay, which was used by them for relaying low frequency, or telephonic, current pulses. It is described in Chap. V. dealing with Low Frequency Amplification, and was first patented in England in January, 1911.

"Audion" Valve.—Dr. De Forest introduced a grid consisting of a perforated cylinder, or plate, between the filament and anode of what was virtually a Fleming valve, thus producing a relaying valve which he called an "Audion." In De Forest's circuit,

which is shown in Fig. 13, the valve is used as a detector-relay : the small pulses of potential set up in the receiver circuit act on the grid and cause corresponding pulses of plate circuit current : these are also rectified by employing the valve at the proper point on its characteristic curve.

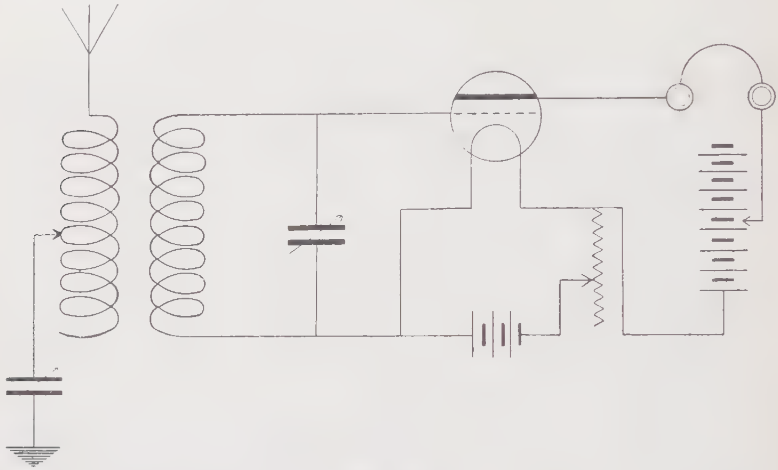


Fig. 13.

Round's Valve.—The soft vacuum Round valve was much superior to any which had preceded it, and was of such a size that comparatively large current pulses were dealt with in the plate filament circuit. It had a hairpin platinum filament coated with a mixture of barium and calcium oxides : completely surrounding the filament was a thimble of fine mesh nickel wire which formed the grid, while a nickel cylinder surrounded this again to form the plate. Like all soft valves it was very sensitive to grid potential, which was regulated by a potentiometer in series with the grid : it was also very sensitive to the degree of vacuum, in other words its sensitiveness depended greatly on the ionisation effects, as has been described in the previous chapter.

In order to counteract the tendency of the valve to harden with continued use a pellet of asbestos was enclosed in a small neck at the top of the valve ; heating this by a match would drive from it gas molecules into the body of the valve, and thus the vacuum could be brought to the proper degree of softness. The necessity of thus regulating the vacuum was a disadvantage, also the facts that when started up the valve did not come into proper

operation until it became warm after two or three minutes, and that the platinum filament was easily burnt out by an improper adjustment of the heating rheostat.

Its filament current was large and its plate required a high voltage compared to other valves then in commercial use, but when properly functioning and in expert hands the results obtained with it were much superior to those given by any other valve.

The valve connections adopted by Round were those of the well-known No. 16 Circuit as used by the Marconi Company. In this circuit Round used his valve to *amplify the high frequency oscillations in the receiver circuit*, a use of the three-electrode valve which appears to have been first disclosed by Armstrong on January 31, 1913, in the United States.

"Pliotron" Valve.—As described in the previous chapter Dr. Irving Langmuir first demonstrated the fact that it was possible to make a valve function even if it had a very hard vacuum; such a valve was constructed under his directions and called by him a "Pliotron." He not only employed the valve as a detector but by the use of two or more valves he obtained amplification of the high frequency oscillations set up in the receiver circuits by the ether waves. In the previous chapter it has been shown that a valve will function as a detector at a point near the lower bend of its plate current curve. To attain this point with many designs of valves a certain negative potential must be applied to the grid by means of a battery or potentiometer in series with it; the higher the plate potential the greater must be the negative grid potential.

Again, a valve will function as a detector at the saturation bend of its plate current curve; in order that the plate current should not be excessive at this point a moderate plate potential is applied, and the filament temperature lowered. The grid should be connected through the oscillating circuit to the lowest potential end of the filament, and the only adjustment required is a rheostat in series with the filament. The resistance is increased and the filament temperature lowered until the saturation bend of the plate current curve exists at the fixed grid potential as shown at point A in Fig. 7. This method is not generally adopted because the steady value of plate circuit current, when no signals are coming in, is higher than that at the lower bend of the curve.

So far we have not considered any action of the grid current curve; a French valve is rarely made to function at either bend of its curve but at the point where the action of the grid current comes into service. Referring again to Fig. 10, suppose the negative

grid potential is adjusted to such a value that the valve is functioning at the point A on its plate current curve. At this point the curve is practically a straight sloping line, at an angle of 45 degrees to both ordinates, hence small oscillations of grid potential will cause corresponding oscillations of plate current, but these will be equal on both sides of A and the mean value of current will not vary. Thus there is no rectifying effect, and for high frequency oscillations, or pulses, no sound will be heard in the telephone receivers. The grid is still at a negative potential of such a value that there is no current to the grid from the filament.

Again, let the grid potential be adjusted to about —4·2 volts, where it is still entirely negative with respect to the filament and just beyond the point at which current starts in the grid circuit. The corresponding plate current is shown at D in Fig. 10; the current here is steeper than at B, and at first sight it would seem as if oscillations of grid potential would now cause larger oscillations of plate current than before, but without changing the mean value of the current. However this is where the action of the grid current must be considered. For negative halves of oscillations of grid potential, *i.e.* to the left of D, the curve shows how the plate current falls, but when positive halves of oscillations act in the grid circuit, tending to bring the grid beyond —4 volts to the right, a grid current flows, *i.e.* electrons flow to the grid, charging it negatively, or wiping out the effect of the positive potential pulse. Thus the grid potential does not rise above —4 volts, the plate current does not rise above D, and therefore received oscillations cause the plate current to oscillate downwards below D but not above it, *i.e. the mean value of the current is reduced,* and thus telephonic pulses formed.

Another way of considering the effect is to say that to negative halves of oscillations the resistance of the grid-filament circuit is infinite and no current flows through it, but for positive halves the resistance breaks down to something between 10,000 and 30,000 ohms and a current flows, damping out these halves of oscillations.

The variation of mean current at D will be greater than at B, because the curve is steeper at this point, hence the valve acts here as a more sensitive or relaying detector; it is evident also that the valve acts as a potential operated device, hence, to obtain the best results, capacity effects must be kept small in the receiver circuit connected across the grid-filament of the valve.

To sum up, the valve will act as a relay-detector at B, or at the saturation bend of its curve; it will give better results as a

relay-detector at D, where the effect of grid current can be employed; at any point on the slope of its curve not too near the bends it will act as a relay of oscillating or pulsing currents, and the point chosen for this purpose should be as low down on the curve as possible to economise plate battery current.

By connecting a small leaky condenser in series with the grid it is possible to make the valve function as a detector-relay, and in

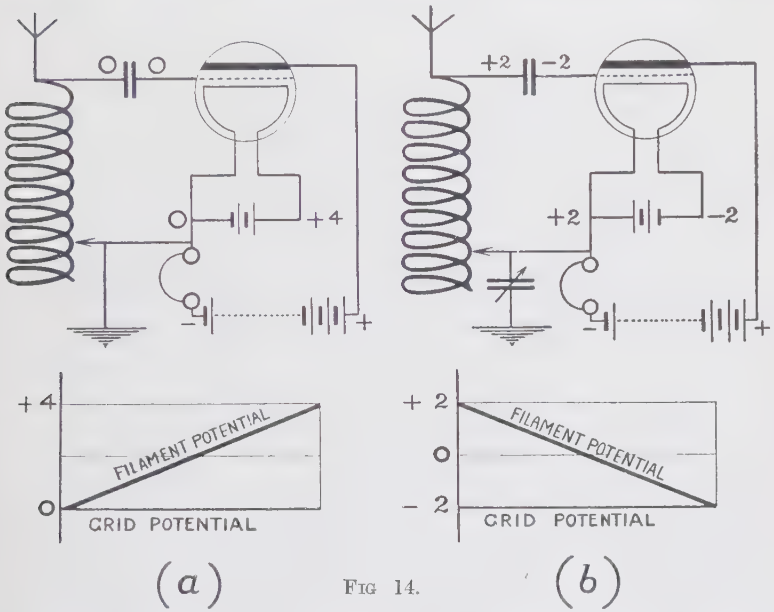


FIG 14.

this case the signals will be stronger than when a grid battery or potentiometer is employed.

Referring to Fig. 14 (*a*) a small condenser is shown in series with the grid, and the negative terminal of the filament battery is connected through the tuning inductance to earth. One end of the filament is now at +4 volts potential, the other end is at zero potential, as also is the grid, so that no part of the filament is at a lower potential than the grid, and the valve is functioning at a point corresponding to D in Fig. 10, where any increase of grid potential will start a grid current.

In Fig. 14 (*b*) the potential gradients are slightly different since an aerial tuning condenser is used; one end of the filament and with it one side of the grid condenser is now at +2 volts, the

other side of the condenser and the grid is at -2 volts. From the gradients shown at the bottom of the figure it is seen that again no part of the filament is below the grid in potential, and that the valve is functioning at point D on the curve of Fig. 10.

In either case suppose a train of ether waves sets up oscillations of potential in the receiver coil, each train of waves representing a spark at the transmitter. The oscillations of potential will be acting in the grid circuit. Suppose the first half of the first oscillation tends to raise the grid potential above the point D in

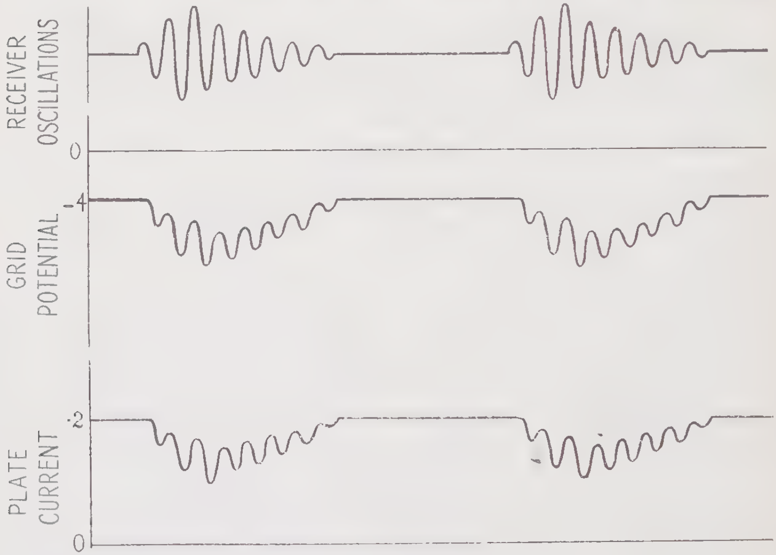


Fig. 15.

Fig. 10; a current flows in the grid circuit, *i.e.* electrons flow to the grid, charging it more negatively and wiping out the positive influence of the half oscillation. Owing to the condenser the charge remains on the grid; when, therefore, the positive half oscillation dies away the grid potential falls to the left of D. The second half of the first oscillation tends to make the grid negative; during it the grid potential swings more to the left and comes back again as the half oscillation dies away. The next half oscillation is again positive; it may be larger than the first but again cannot raise the grid potential beyond D, as any tendency to do so only draws more electrons to the grid to charge it more negatively. Thus, as shown in Fig. 15, during the first few oscillations the mean value of grid

potential actually falls, but as the oscillations in the train die away the grid potential rises again owing to leakage of its charge. The changes of grid potential is accompanied by corresponding changes in the plate current, giving, at each train of waves, a pulse downwards which actuates the telephone diaphragms.

It is difficult to find an analogy for this action, but the following may serve :—

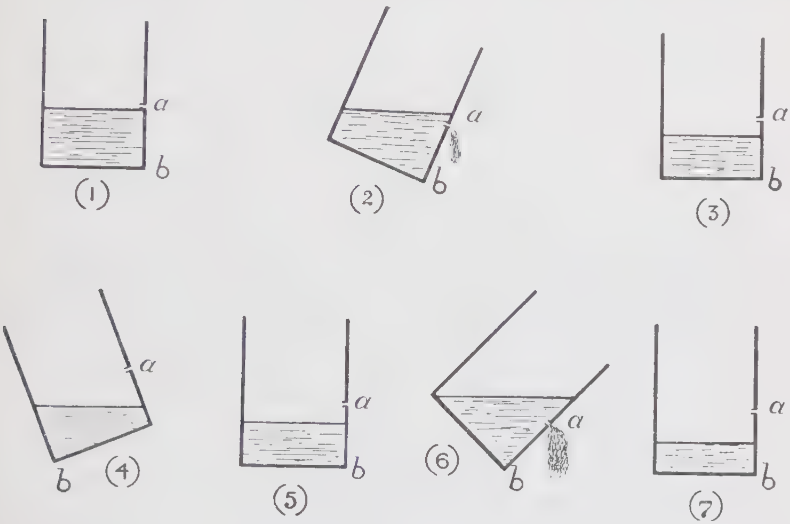


FIG. 16.

Suppose that we have a small vessel filled with water just up to a hole in the side as in Fig. 16 (1) at *a*, and let us consider the pressure of water on the bottom at *b* if an attempt is made to raise and lower this pressure by oscillating the vessel. When the vessel is tilted over so as to increase the pressure, Fig. 16 (2), water runs out of the hole and the pressure is not increased. (This corresponds to a negative charge flowing to the grid when its potential tends to rise above D in Fig. 10.) When the vessel returns to normal, as at 16 (3), the pressure at *b* is less than it was before ; on swinging it to the other side, 16 (4), the pressure at *b* decreases, but comes up again when it returns to the normal, 16 (5). On swinging it again to the right, 16 (6), if this oscillation is greater than the first more water spills out, and on returning to the normal, 16 7), the pressure at *b* is less than ever. If the oscillations now get smaller and die away the pressure at *b*

oscillates, but if at the same time water leaks back into the vessel it quickly rises to the initial value, during the fading out of the oscillations. In much the same way the negative potential of the grid of a valve, connected as in Fig. 14, will increase when oscillations are impressed on it, but will rise again to normal owing to leakage as the oscillations die away.

The grid condenser must be very small so that it will rapidly attain a negative potential of $(-4-e)$ volts, where e is the maximum oscillation of potential just as the pressure changes for small oscillations of the water vessel will be greater the smaller the vessel.

The action above described presupposes that the extra charge on the grid will leak off during the damping of the oscillations due to a wave train, and that the grid will have returned to its normal potential before the next train arrives. If the condenser plates are well insulated this leakage will not occur with sufficient rapidity, so that it is generally necessary to shunt the condenser with a leakage path of high resistance, whose value will depend upon the size of the condenser, as shown later.

If a suitable leak were not provided strong discharges, such as atmospherics, would bring the negative potential of the grid to such a value that the plate current would be reduced to zero; the valve would then be *paralysed* and remain so until the slow leakage from the grid brought it back to its normal potential. In this paralysed condition the negative grid repels electrons, so that those emitted from the filament build up a negative field between it and the grid, or return again to the filament, and none pass to the plate.

It is easily recognised that when a grid condenser is employed the sensitiveness of the arrangement, as a detector-relay, greatly depends on the proper design of condenser and leak shunt; also on the assembly of connecting wires, etc., so that no other uncalculated capacity effect comes into action. A leaky grid condenser may be used with gas, or soft vacuum, valves, and it may be noted that, in these, positive ionisation helps to prevent an accumulation of negative potential on the grid so that a leak may not be necessary.

When a series grid condenser is employed the reactance of the condenser should be less than the apparent resistance between the grid and filament in the valve itself; under reception conditions this resistance is of the order of 200,000 ohms. Now condenser reactance equals $\frac{1}{2\pi f K}$, hence the smaller the condenser the greater its reactance. Also it is seen that the reactance will increase with

the frequency; it is therefore higher, and the valve detector is less sensitive, for short wave working than for long wave working. Another consideration as regards the size of the series grid condenser is that it should be very much greater than the capacity effect in the valve itself, otherwise potential variations will not be transmitted by it to the grid with full effect. The grid capacity effect in a French valve under reception conditions is of the order of 0·000015 mfd.

On the other hand the series grid condenser must not be too large, because the oscillations would not then have a great effect on its potential. Its size, within the limits pointed out above, should really depend on the amplitude of the oscillations, *i.e.* on the strength of signals. The French military authorities have used a capacity of 0·00004 mfd., but for all-round working the author has found that 0·0003 mfd. is a suitable value.

The value of the leak resistance will depend upon the capacity of the condenser which it shunts. It is necessary that the high frequency oscillating currents should flow through the condenser rather than through the leak, therefore the reactance of the condenser in ohms should be small compared to the resistance of the path shunted across it. For example, suppose signals on 600 metres wave length are to be received and that the grid condenser is 0·0003 mfd. The reactance of the condenser path to the oscillations is :—

$$\frac{1}{2\pi f K} = \frac{1 \times 10^6}{6{\cdot}28 \times 500000 \times 0{\cdot}0003} = \frac{10000}{9} = 1111 \text{ ohms approx.}$$

This is therefore small compared to the shunt of 3 megohms across the condenser.

Even if the condenser is only 0·00005 mfd., the reactance is of the order of 6666 ohms to oscillations at a frequency of 500,000 and a leak shunt of 4 megohms is still suitable.

Let us return for a moment to the use of a valve as a detector without a series grid condenser, and study the relation between the strength of the signals and the amplitude of the oscillations set up by the received energy in the aerial, or tuned circuit, to which the valve is applied. It has already been pointed out in Chap. II. that if the characteristic curve of a hard valve is drawn, and measurements made of the values of plate current increases corresponding to grid potential increases, starting from a point near the bend of the curve, it will be found that the changes of current are nearly proportional to the squares of the changes

of the grid potential. Thus the valve is, like the crystal detector, a potential operated device, and the strength of the signals is proportional to the square of the oscillation amplitude.

Perhaps this can be shown more clearly if the question is dealt with mathematically. Let the grid be at an initial potential v and the corresponding plate current i, the latter being the steady current in the plate circuit when no signals are arriving. The equation of the curve at this point can be written $i=f(v)$. When signals arrive very small oscillations of increase and decrease of grid potential occur; let the maximum oscillation value in the positive direction be dv, and the corresponding increase of plate current be di. Then $i+di=f(v+dv)$. Expanding the right-hand side of this equation to three terms we have :—

$$i + di = f(v) + dvf'(v) + \frac{dv^2}{2}f''(v)$$

But $i = f(v)$, therefore :—

$$di = dvf'(v) + \frac{dv^2}{2}f''(v)$$

Now $d(v)$ represents an oscillating voltage so that its mean value is zero, whereas $\frac{dv^2}{2}$ is always positive. Therefore the mean value of the change of plate current (di) is determined by the mean value of $\frac{dv^2}{2}f''(v)$, which depends on the square of the amplitude of oscillation.

Also the expression $\frac{dv^2}{2}f''(v)$ will be greatest when $f''(v)$ is maximum; this will occur not at the bend of the curve but at the point where the tangent is most inclined to the horizontal, *i.e.* where the rise of the curve is steepest.

When the valve is made to function as a detector near the bend of the grid current characteristic curve, having a leaky condenser in series with the grid, it can be shown by methods similar to those given above that the strength of the signals is proportional to the square of the amplitude of oscillation.

As a matter of fact, when a high resistance, shunted by a small condenser, is connected in series in the grid circuit it is not generally the case that the valve is functioning just at the point at which the grid current is zero, nor is it necessary that it should function exactly at this point.

Let us consider the matter in this way: Suppose that the filament has 4 volts applied to it and that the grid is connected through a high resistance to the positive end of it. The grid will be higher in potential than the negative end of the filament and therefore some electrons will flow to the grid. If the high resistance is r and the grid current is C_g the volts used up in the high resistance is $C_g r$ and the grid potential is $4 - C_g r$ compared to the negative end of the filament. The valve is now functioning at some point E in Fig. 10, where a small current is flowing in the grid circuit, as well as the current in the plate circuit. Oscillations of potential in the receiver circuit, to which the grid and filament are connected, will be transmitted through the small condenser to the grid. Positive pulses of potential will draw extra electrons to the grid, negative pulses will not; the extra charges on the grid will leak through the high resistance increasing the value of $C_g r$, therefore the grid potential $(4 - C_g r)$ is reduced causing a pulse of reduction of plate current and signals in the telephones. As soon as the extra charge has leaked off through the resistance the grid returns to its normal potential, and for spark signals the resistance should be of such a value that this can take place during the interval between sparks.

Even when a small grid current is flowing, under the conditions described above, the grid circuit of a French valve has a resistance of the order of 200,000 ohms, so that it will have little damping effect on the oscillating circuit and tuning is sharp. When used as a detector the plate circuit has a resistance of 20,000–25,000 ohms, hence the impedance of the telephone receivers, or the telephone transformer coil, connected in series with it should have an impedance of this order at a frequency of 600–1000.

For reasons which will be explained presently it would be better not to connect the telephone receivers directly in series in the plate circuit, but to connect them to this circuit through the medium of a telephone transformer; also to shunt the primary of this transformer and the H.T. battery by a small blocking condenser. With these modifications the circuit of Fig. 9 becomes that shown in Fig. 17, where PS is the telephone transformer, and K is a blocking condenser shunting the primary, P, of this transformer and the H.T. battery in series.

As regards the advantages of using a telephone transformer, it may be recalled that there is always a steady value of plate circuit current when signals are not arriving, and if the telephone receivers are connected directly in the plate circuit this current

will flow through them. Such an arrangement has three obvious disadvantages. In the first place, since the receivers must be high resistance ones the insulation of the receiver coils will be very light, and the comparatively high potentials employed in the plate circuit are liable to break down this insulation, especially when the receivers are damp. They always do become damp from condensation when worn for any length of time. Secondly, telephone receivers have a distinct polarity since their coils are wound on the poles of permanent magnets ; hence, if due attention is not paid to this polarity when connecting the receivers to the plate circuit, the steady current flowing in the plate circuit may be demagnetising the receivers all the time they are connected up.

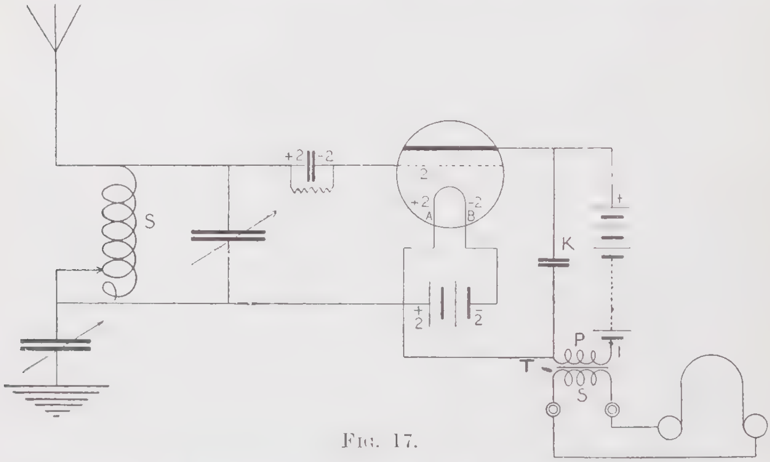


Fig. 17.

If the receivers are connected to the secondary of a telephone transformer this cannot happen, since a steady current in the primary gives no induction and a current will flow in the secondary circuit only when pulses of primary current occur, *i.e.* only when signals arrive. Lastly, if the receivers are connected directly in the plate circuit, as shown in Fig. 9, it is evident that if a metal headband is employed this will be earthed through the operator who wears it ; when the insulation is weak, as it is liable to be when damp, this may seriously interfere with the potential gradient between the plate and the filament.

Even if the telephone receivers are connected into the circuit with correct polarity the steady current which flows through their coils may have the effect of decreasing their sensitivity. Let us

consider why the telephone coils are wound on the poles of a permanent magnet. If M_1 = magnetic flux due to the permanent magnet, and $M_2 \sin pt$ = flux due to a pulsating current in the coils at any instant, the effect on the diaphragms is proportional to $(M_1+M_2 \sin pt)^2 = M_1^2+2M_1M_2 \sin pt+M_2^2 \sin pt^2$. Neglecting the last term as being very small we see that the portion of the force on the diaphragm which is changeable and causes them to vibrate is $2M_1M_2 \sin pt$, *i.e.* it is proportional to M_1. This is true only for small displacements of the diaphragm and only up to a certain point: the effect cannot be increased indefinitely by increasing M_1 since the diaphragm may soon become saturated. If there is a steady current in the coils it may increase the magnetic flux due to the permanent magnet so that the diaphragm may be saturated, and under these conditions it will not respond readily to small changes of magnetic flux caused by pulses in the current.

From insulation considerations it is always best to take the precaution when connecting up the plate circuit to join the plate directly to the + pole of the H.T. battery, and then connect any auxiliary apparatus which may be included in the circuit, such as a telephone transformer, between the H.T. battery and the filament. It is usual to take advantage of the use of a telephone transformer so as to have a step-down ratio from primary to secondary, enabling us to use 60 ohm, or low resistance, telephone receivers instead of the 4000 or 8000 ohm ones. The low resistance receivers are not so mechanically delicate and not so expensive as the high resistance ones, but whether it is an advantage to use such a large step-down ratio must depend on the relative electrical sensitiveness of high and low resistance receivers. If the telephone receivers are connected directly in the plate circuit then they must be of high impedance, since the resistance of the value between plate and filament under reception conditions is of the order 20,000–30,000 ohms and the current effects very small.

As regards the blocking condenser K, if Figs. 11 and 13 are referred to it will be seen that the high frequency oscillations of grid potential produce corresponding oscillations in the plate current. These oscillations can have no effect on the vibrations of the receiver diaphragms since they are of high frequency. It may be thought that the high impedance to oscillating currents of the receiver coils, or the telephone transformer primary as the case may be, would damp out these small oscillations. While not entirely so this is the case to a large extent; if it is desired to have the high frequency oscillations freely reproduced in the

plate circuit current a path of low impedance must be provided for them. This is conveniently done by putting a small condenser (say 0·002 mfd.) as a shunt across the high impedance portion of the circuit; the main pulses of plate current will now go through the battery and primary of the telephone transformer, while the high frequency pulses will go through the condenser; both combining in all other parts of the circuit.

The reactance of a condenser to oscillating currents is $\frac{1}{2\pi f K}$ ohms, where f = the oscillation frequency, K the capacity in farads, and $\pi = 3{\cdot}14$. As an example, suppose that signals on 600 metres wave length are being received; $\lambda \times f = 300{,}000{,}000$, therefore f in this case $= 500{,}000$. If the condenser is 0·004 mfd. its reactance to the oscillations $= \frac{10^9}{6{\cdot}3 \times 500{,}000 \times 4} = 80$ ohms approximately. But if the spark rate is 500 per second, the pulse frequency in the receiver is 500 and the reactance of the condenser to the pulses is $\frac{10^9}{6{\cdot}3 \times 500 \times 4} = 80{,}000$ ohms. Thus the oscillations pass easily through the condenser while the pulses meet with a high resistance. The reactance of a coil to oscillating currents is approximately $2\pi f L$ ohms, and it is easily seen that this is less for low frequency pulses than for high frequency oscillations, so that the pulses can pass more easily through the primary of the telephone transformer than through the condenser.

The condenser is usually made of copper or tin foil sheets separated by thin mica dielectric, the whole being firmly clamped by screws between ebonite sheets. Apart from the fact that it serves to conduct, or by-pass, the high frequency oscillations in the plate circuit current, it will act also in the usual manner of a blocking condenser to improve the note in the telephones.

The grid condenser can be conveniently made with 9 strips of copper or tinfoil, $1\frac{3}{8}'' \times \frac{5}{8}''$ each, separated from each other by 11 mica sheets, $1\frac{3}{4}'' \times 1''$ and 0·004″ thick, alternate plates being connected together. This will form a condenser of about 0·0003 microfarad capacity; preferably the whole should be held firmly between two metal or ebonite plates screwed together, so that the capacity is not likely to change owing to a variation in the distance between the plates.

The leak across the condenser can be made by having a thick line of Indian or Chinese ink on a strip of paper, the ends of which are clamped between two metal plates or terminals; the paper

can be cut to a breadth and size to give the necessary resistance, *i.e.* from 2 to 3 megohms, and the whole enclosed in a block of paraffin wax. Another method is to scratch a deep line on a piece of ebonite with a knife, about $2\frac{3}{4}''$ long, and then draw a pencil mark with a hard graphite pencil on the line, thickening it until the desired resistance is obtained. This should be covered with another sheet of ebonite, screwed down, and the whole made watertight by painting the edges with melted paraffin wax. This method is crude and the resistance is likely to change with moisture, vibration, etc.: a better method is to use platinised glass, *i.e.* glass on which a very thin coating of platinum has been deposited by an electrolytic process. The French have used a grid condenser as

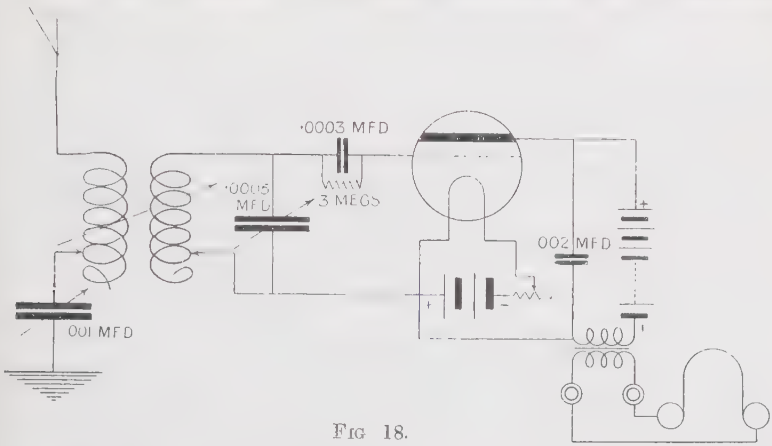


FIG 18.

small as 0·000002 mfd. with a leak of 1 megohm, but in the author's experience, especially with the valve giving high frequency amplification, as described in the next chapter, the best values are about 0·0003 mfd. and 3 megohms respectively. The leaky grid condenser may be connected anywhere in the grid filament circuit, that is to say, in Fig. 17 it may be connected in the lead which connects the bottom of the aerial tuning coil to the filament.

As it functions by very small potential effects it must be carefully insulated, and not fixed near moving conductors such as the hand of the operator.

The valve may be used as a detector across a coupled secondary circuit instead of across the aerial inductance, in which case the connections will be as shown in Fig. 18.

Fig. 19 shows one method employed by the Marconi Company

for the use of a small "Q" valve as a detector; the first "Q" valve, designed by Round, is described in Chap. VI. The apparatus shown can be mounted on a slab, and the terminals T_1, T_2, connected across the wireless receiver circuit. The necessary grid potential was obtained by means of the potentiometer, and there was also a rheostat for controlling the filament heating, and tappings on the 150 volt battery so that the adjustment of the valve to function at a proper rectifying point can be made with great accuracy. The original "Q" valve had a curve which rose comparatively steeply from its critical point when 150 volts were applied to the plate, so that it was quite a good detector.

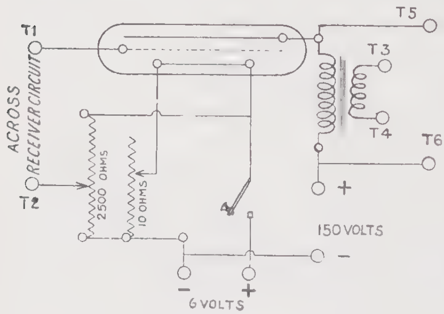


FIG. 19.

The telephone receivers can be connected to the terminals T_3, T_4, of the step-down transformer, but if it is desired to have low frequency amplification the terminals T_1, T_3, are connected across the grid-filament of the first valve of a low frequency amplifier, and the receivers connected to the proper terminals on the latter.

The "Q" valve and its auxiliary apparatus have been modified in design, so that it now functions on normal plate potentials.

QUESTIONS ON CHAPTER III.

1. Compare valve and crystal detectors as regards their damping effect on the oscillations. On what does the damping effect of a valve depend?

2. What are the disadvantages of soft vacuum valves?

3. Describe shortly how a valve may be made to function as a detector at either of three points on its characteristic curve. Which point will give the most efficient results?

4. Why are the small coils in a telephone receiver wound on the poles of a permanent magnet and not on an ordinary soft iron core?

5. What are the advantages of using a telephone transformer in a valve receiver circuit?

6. If the telephone transformer is shunted by a condenser, why do not the current pulses go through the condenser rather than through the transformer?

7. What are the considerations on which the size of a series grid condenser is based?

8. If a series grid condenser is used with a valve, how does this effect the plate current valve? Can the plate current now rise to ordinary values of saturation? If not, on what does its value depend?

9. If a valve rectifies well with zero potential on the grid and no series grid condenser, what does this demonstrate concerning (*a*) its plate current characteristic, (*b*) its design?

CHAPTER IV

HIGH FREQUENCY AMPLIFICATION, OR AMPLIFICATION OF THE OSCILLATIONS

A REFERENCE to Figs. 11 and 15 will show that every oscillation of grid potential in a valve produces a corresponding oscillation in the plate current, which may be accompanied by a low frequency pulse in the mean value of the plate current if the valve is made to function at a rectifying point on its curve. The amplitude of these high frequency oscillations in the plate circuit is increased by providing a low impedance condenser path for them in parallel with the high impedance parts of the plate circuit, as shown in Figs. 17 and 18, Chap. III. Thus the valve may be used only as an amplifier of H.F. oscillations if it is made to function at a point on its characteristic curve at which rectification does not take place. The oscillations set up in the plate circuit will be of larger amplitude than those acting on the grid circuit ; in fact an aerial circuit can be coupled to a secondary circuit, which is included in the plate circuit, simply through the medium of an amplifying valve.

The oscillations in the plate circuit current are exactly in synchronism with the oscillations of grid potential ; the latter are induced by the oscillating currents set up in the receiver aerial circuit by the ether waves, so that the plate circuit oscillations have the same frequency as the ether waves, and can be employed to assist them.

In Fig. 20 let the plate circuit include a coil of low impedance, R, which can be coupled to the aerial tuning coil, XY ; then any oscillations in R will induce an oscillating difference of potential at the terminals XY of the A.T.I. coil by simple transformer action. But the received ether waves are setting up oscillating currents in the aerial circuit, and as these flow through the A.T.I. they give an oscillating difference of potential across XY. Thus in the arrangements as shown in Fig. 20 oscillating potentials are induced

in the A.T.I. by the ether waves; these act on the grid of the valve and cause oscillations of the current in the plate circuit; the latter flowing in the reaction coil R induce oscillating potentials in the A.T.I. which amplify the oscillating effect already induced in it by the ether waves. With this arrangement it is possible to receive signals over long ranges which would be inaudible if the ether waves alone were relied upon to set up oscillations of the grid potential of the valve.

The coil R is generally called a *reaction coil*,[1] and care must be taken that it is turned the right way round to the A.T.I., otherwise

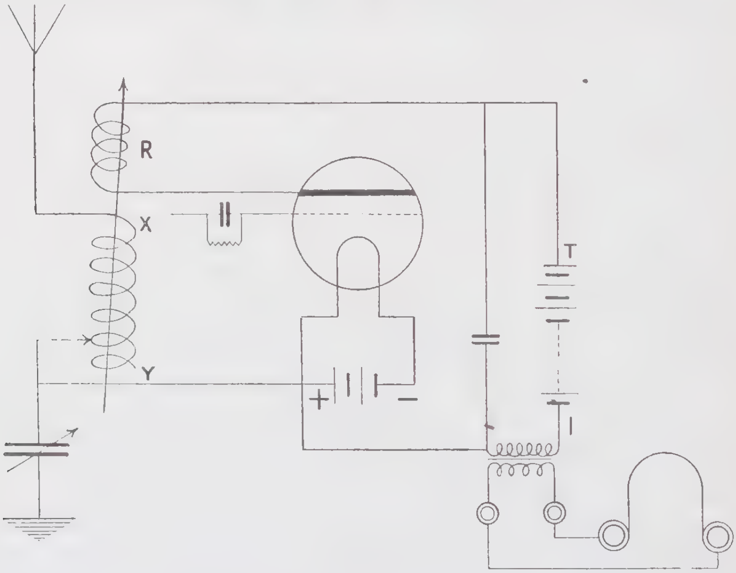


Fig. 20.

the oscillations in the plate circuit will directly oppose the effects of the ether waves on the A.T.I. and the signals will be wiped out. Generally the coupling of R with the A.T.I. is adjustable so that the amplifying effects produced by it can be varied.

Since the amplitude of the high frequency oscillations is increased by this means it is generally termed High Frequency Amplification. It is also to be noted that since the amplitudes of the oscillations are increased they will persist longer in the receiver aerial; that is to say, there will be more oscillations per wave train and the damping is decreased.

[1] In the United States it is sometimes called the "tickler coil."

This reaction back effect was first employed by Edwin Armstrong of Columbia University in 1913, and is often referred to as Armstrong's Feed Back Circuit.

In England one of the earliest and best examples of high frequency amplification was the now famous No. 16 Circuit (adopted by Round for use with his soft vacuum valve); this circuit is extensively employed by the Marconi Company. In it the valve is used to amplify the high frequency oscillations and not as a detector; while it may set up low frequency pulses to

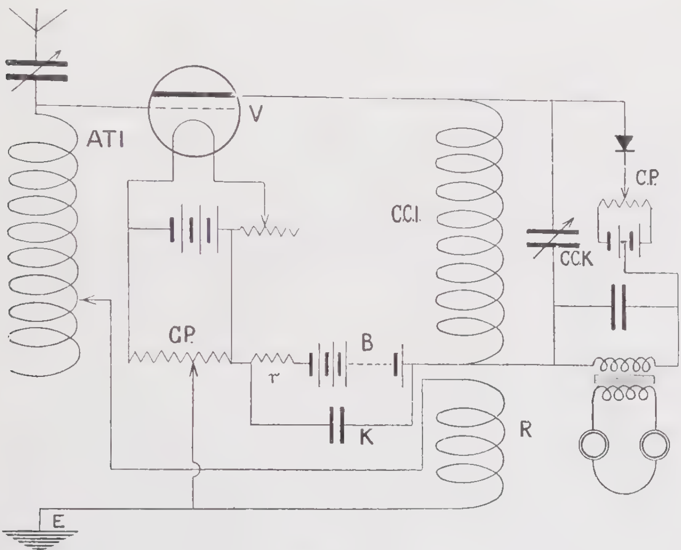


Fig. 21.

some extent, the main rectifying effects are obtained by the usual combination of carborundum detector and potentiometer.

The circuit is as shown in Fig. 21; the battery which heats the filament also supplies voltage across the grid potentiometer, to which the grid is connected through the A.T.I. and coupling coil R. The potential of the grid with respect to the filament can be adjusted by means of the potentiometer, GP, to give best results.

The plate-filament circuit includes the closed circuit inductance, C.C.I., in series with the high tension battery, B, and a high resistance, *r*, of 2000 to 4000 ohms. This resistance is necessary with Round's soft vacuum valve in order to limit the valve of plate

current, which would otherwise become excessive when, for any reason such as overheating, the vacuum of the valve is too soft.

A condenser, K, provides a path of low impedance for small high frequency oscillations of current in the plate circuit. When a train of ether waves acts on the aerial circuit it induces oscillating potentials in the A.T.I. coil, and therefore oscillating potentials on the grid of the valve. This sets up corresponding oscillations in the plate-filament current which flows through the C.C.I. coil. The oscillating energy in C.C.I. induces into the coupling coil R so that some of it is transferred into the aerial circuit, to amplify there the effects of the ether wave train. In other words, some of the energy of the battery B is turned into oscillating energy, and put into the aerial circuit to augment the oscillations set up in it by the energy transmitted through the ether. The result is a greater oscillating effect on the grid potential and, therefore, a greater effect in the closed tuned circuit C.C.I. and C.C.K. The current in the closed circuit is then rectified by the crystal detector in the usual manner and discharged through the primary of the telephone transformer. It may be noted that if the valve V, with its batteries and potentiometer, is not in use the circuit becomes an ordinary crystal receiver circuit, the coil R acting as a coupling between the aerial and closed circuits.

The connections shown in Fig. 21 give what is sometimes called "Single Magnification"; by the introduction of a second telephone transformer it is possible to obtain "Double Magnification"—that is to say, the valve is employed to amplify the low frequency pulses as well as the high frequency oscillations. Though not purely high frequency amplification the "Double Magnification" connections will be described here, as it is interesting to compare them with Fig. 21. They are shown in Fig. 22, and it will be seen that the secondary of the original telephone transformer T is now connected in the grid circuit at X (as shown by the dotted lines), whilst the telephone receivers are joined through a telephone transformer in the plate circuit Y.

As before, when ether wave trains act on the aerial circuit pulses of current are set up in the plate-filament current of the valve at the wave train, or spark, frequency, on which are superimposed oscillations at exactly the frequency of the ether waves. The superimposed oscillations flow through the condenser K and coil C.C.I., and are made to react back, or impart energy, through the coil R into the aerial circuit, thus amplifying and augmenting the oscillations set up in the latter by the ether waves. The larger low

frequency pulses in the plate circuit current are rectified by the detector and pass through the transformer T to be transferred back to the grid circuit; the resulting pulses of grid potential cause a corresponding amplification of the filament-plate current pulses which act through the telephone receivers at Y.

It may be noted here that the hard vacuum French valve is not as good as the Round valve for work on a double magnification circuit of this description.

In Chap. II. it has been remarked that Armstrong was one

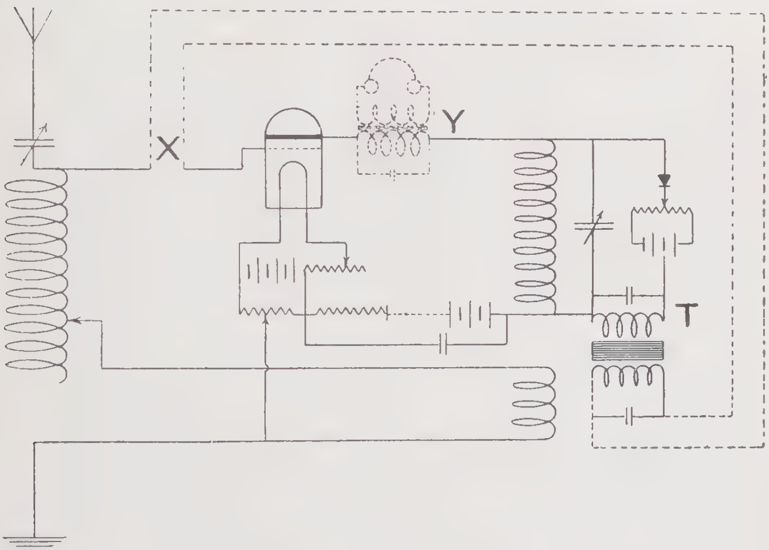


Fig. 22.

of the first to use hard valves, and to make the valves carry out all the functions of a detector-amplifier-relay without the help of a crystal detector. One of Armstrong's methods is shown in Fig. 23. The grid and filament are connected across the closed circuit of the wireless receiver, the grid having a small condenser, C_1, in series with it. The plate-filament circuit contains a reaction coil, L_1, which is coupled to a portion (L_1) of the inductance in the receiver closed circuit. The high resistance telephone receivers, T, are shunted by a condenser, C_2, which provides a path for the high frequency oscillations set up in the plate circuit. These oscillations flow through L_2 and react back into the receiver circuits

through L_1. The closed circuit could be omitted if desired, and the coil L_2 made to react into a portion, or the whole, of the aerial tuning inductance, across which the grid and filament would then be connected. The arrangement would be improved by having a high resistance leak across the grid condenser C_1; also by making the condenser C_2 shunt the H.T. battery as well as the telephone receivers. It would be better also to rearrange the plate circuit so that the sequence is plate, reaction coil (L_2), H.T. battery, receivers, filament, instead of having it as shown with the reaction coil in the lowest potential part of the circuit. Lastly, the telephone

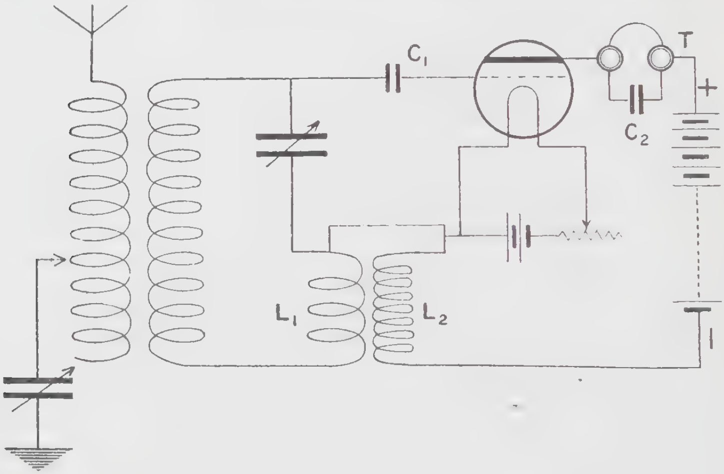


FIG. 23.

receivers should not be connected directly in the plate circuit but through the medium of a telephone transformer (preferably a step-down transformer so that low resistance telephones may be used), for reasons already explained.

Before proceeding further a comparison of Round's No. 16 Circuit with that of Armstrong will show that in the latter all troubles with poor crystals and crystal detector adjustments are avoided. The hard vacuum valve when properly adjusted for sensitive working gives no trouble, and its life is very long. But, as already discussed, a valve may not be as good a rectifier as a good crystal combination, therefore the No. 16 Circuit is likely to give stronger signals than any circuit in which a valve alone is used to rectify and give amplification effects at the same time. Also

the good results obtained with a Round valve on a No. 16 Circuit are largely due to the fact that the soft valve, when properly adjusted, has a steep characteristic and amplifies well, and since it is not required to rectify it can be used on that portion of its characteristic curve where the amplifying properties are best.

It is equally true that if a hard valve, such as the French valve, is used on a No. 16 Circuit stronger signals will be obtained than if the valve were used alone, provided the crystal detector is good and properly adjusted. At the same time a method which provides for the elimination of all crystal and potentiometer trouble is a distinct advance, especially as the strength of signals can be easily brought up by means of valve amplifiers. A circuit similar to

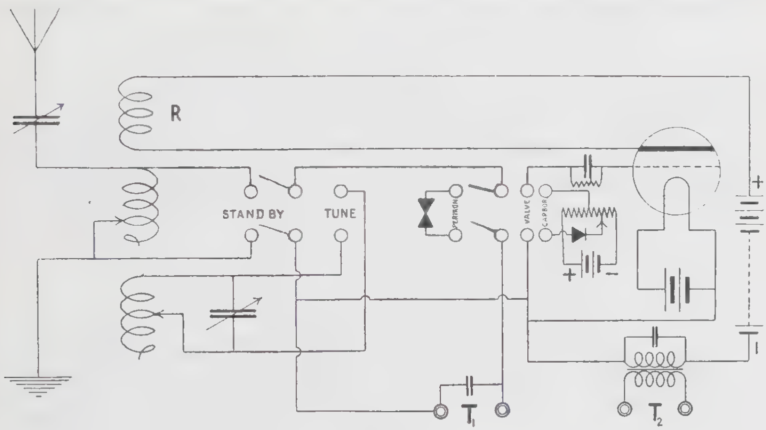


FIG. 24.

that shown in Fig. 23 was patented by Round in 1913, but was not used by him at that time, probably because the Round soft vacuum valve gave better results with a No. 16 Circuit. In Round's patent of 1913 a variable condenser was connected across the reaction coil in the plate circuit so that this could be tuned to the frequency of the oscillations, thus increasing the amplifying effects.

The connections of a receiver in which either a valve or crystal detector can be used are shown in Fig. 24; this receiver was designed to work on wave lengths up to 700 metres, with an aerial from 60 to 120 metres long.

A change-over switch is provided for "Stand By" or "Tune" connections, and either the Perikon or the carborundum detector

can be employed with high resistance telephones connected to the terminals marked T_1. If it is desired to use the valve the detector switch is put to the valve contacts and a pair of 60-ohm telephone receivers connected to the terminals marked T_2 – which are reserved for the valve circuit. The valve filament is connected to a 4-volt battery direct ; the grid condenser is 0·0004 mfd. with a 3-megohm leak across it. The reactance coil, R, is of spherical shape 2⅝″ diameter, fitting into, and half enclosed by, one end of the aerial tuning inductance coil, and wound with 100 turns of No. 26 D.S.C. copper wire ; the coil can be rotated through 180° and carries a pointer on its spindle to show the degree of reaction coupling on the top of the receiver.

The telephone transformer is the standard Marconi military pattern type ; the shunt condenser across the transformer and the high tension battery has a capacity of 0·002 mfd.

To use the valve the circuit switch on the tuner is put to "Stand By," and the detector switch in the valve contacts ; a 4-volt battery is connected to the filament terminals and a high tension battery to the H.T. terminals—care being taken that both are connected up with proper polarity. About 50 volts from the H.T. should be plugged in and the aerial circuit tuned in the ordinary way until signals are heard.

The reaction coil should then be rotated until a position for it is found at which the signals are at a maximum without losing the quality of the note. This position should be noted as it will always be approximately the best adjustment of the reactance coil. If desired the tuner switch can now be turned to "Tune" and the closed circuit used in the ordinary way.

A valve on a reaction receiver circuit is most sensitive when it is just on the point of generating oscillations ; this can be determined by moving the aerial inductance switch across its studs, when, if the valve is oscillating, faint clicks will be heard as the switch passes from stud to stud. If these clicks are not heard the reactance coupling should be increased, while if the clicks are strong the coupling should be loosened, or the plate potential decreased until they are just discernible. If a milliammeter is included in the plate circuit, it will show a decrease of plate current when the valve starts oscillating with an increase of reaction coupling. This is due to a fall of grid potential when the oscillations allow electrons to flow to the grid, charging it negatively. In the telephone receiver a dull click is heard when the reaction coupling is such that oscillations are started in the valve. The best method

of adjustment is by received signals, either from a distant station or from a wavemeter buzzer.

The received signals will increase in strength as the reactance is increased, but beyond a certain value of reaction coupling it will be found that whilst the signals increase in loudness they lose the quality of the transmitted note and become harsh and crackling. In such circumstances it is impossible, for instance, to distinguish the note as that of a German, French, or British station. The reason is that the reaction between plate and grid circuit is too great, the valve is generating oscillations, and the low harsh note is caused by beat effects between the two sets of oscillations—those set up by the ether waves and those generated by the valve itself.

Spark signals are not carried on one wave length but on a range of wave lengths which may be broad or narrow according to the sharpness of tuning; thus oscillations of frequencies above and below the main oscillation frequency will be set up in the receiver circuit, and each of these combining with the oscillations generated in the valve will form a beat or pulse of audible frequency. Therefore a number of beats are set up and the result in the telephones is a harsh note rather than a pure one.

This effect of an oscillating valve on received signals is called "heterodyning"; to avoid it the reactance should not be so tightly coupled that the valve generates oscillations; that is to say adjustment should be made, not for extreme loudness of signals, but rather for signals which can be comfortably read without losing the quality of their note, so that the nature of the transmitting station can be distinguished. The valve as a generator of oscillations and the formation of "beats" will be more fully dealt with in later chapters.

It will be found that if the aerial circuit is broken when the reaction coil is set at its working position the valve yowls. This is because the potential of the grid is oscillating strongly; it is being charged by electrons from the filament which do not leak off it with sufficient rapidity, and thus the plate current is reduced to zero at an audible periodicity, causing a high note in the telephone receivers. The same thing will generally occur if the aerial tuning condenser is set at a very small value, since this condenser is in series with the aerial and setting it at a low value practically breaks the aerial circuit. The aerial acts as a condenser across the valve circuit and capacity effects always tend to reduce oscillations; thus if the reaction is set so that the valve is just on the point of oscillating a decrease of capacity effect in its circuit will produce

strong oscillations. This will be more fully discussed in a subsequent chapter.

With the reaction coil coupled to the A.T.I., as shown in Fig. 24, the amplification will be small for short wave signals, since the A.T.I. will then be tuned down to a small value and this reduces the coupling effect; with short waves, therefore, the reaction coil should be coupled tighter to the A.T.I. than for longer waves.

The reaction coil may be put in the grid circuit, the plate circuit being connected to the tuned receiver circuit as shown in Fig. 25. This does not give as good results on spark signals as

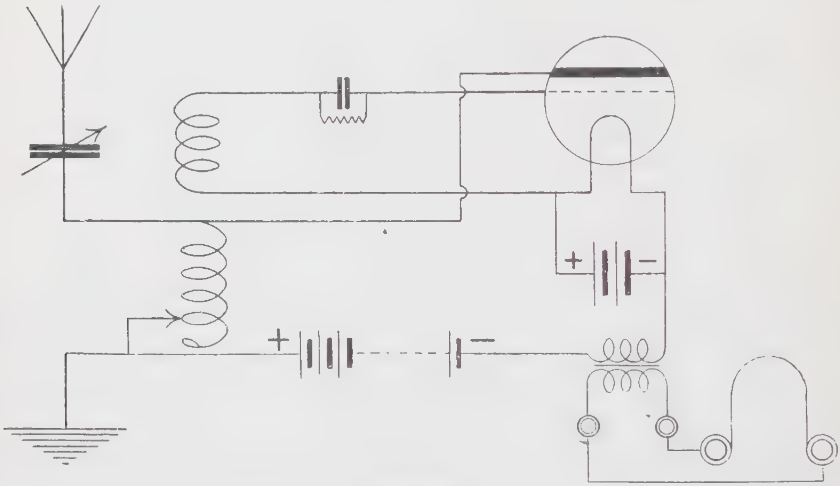


Fig. 25.

when the plate circuit is reacting. It is however an arrangement sometimes adopted for receiving C.W. signals.

An obvious method of obtaining amplification of weak oscillations is shown in Fig. 26, and implies the use of two valves in cascade. The first valve has negative potential applied to its grid by means of a potentiometer in the grid circuit; it is made to function at a point on its characteristic curve where the oscillations of grid potential are relayed in the plate circuit without being rectified. Thus amplified oscillations are obtained in the plate circuit and they will set up strong oscillations of potential across the inductance S which can be tuned to them. The tuned circuit on the plate of the first valve is coupled to the first tuned circuit on the grid of the first valve through the valve action, and the

oscillations are amplified F times by this coupling—where F is the amplifying factor of the valve.

The oscillations of potential in S are then applied to the grid of a second valve, the grid having a leaky condenser in series with it so that the second valve has about —4 volts potential on the grid; it functions at point D in the curve of Fig. 10, therefore rectifies and acts as a detector.

This arrangement is interesting because two valves are carrying out different functions, and it explains clearly what is required in each case. By a little re-arrangement, with rheostat coil, one 6-volt battery could be used to light both filaments and supply the potential drop in the grid potentiometer of the first valve.

The first valve will require either fairly high volts, say 75 to

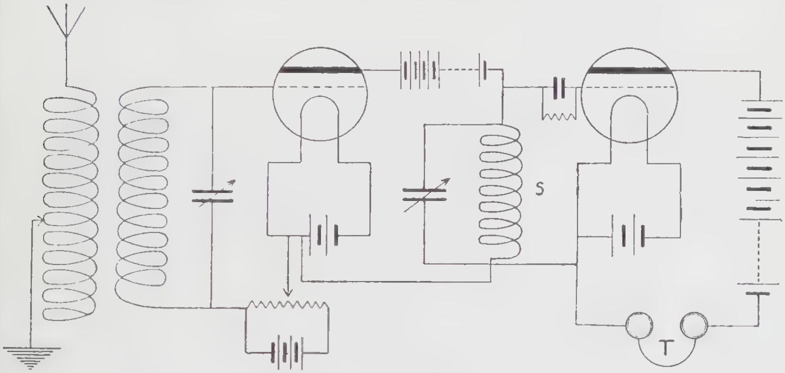


FIG. 26.

100, in the plate circuit, or fairly high filament temperature, in order to obtain a steep curve so that the amplification of the relayed oscillations may be as large as possible. The second valve will not require so high a voltage since it will be employed near the lower bend of its curve; one might, however, obtain the proper point on a curve by lowering the filament temperature, if by doing so we get the grid at the corresponding correct negative potential to give rectification. Thus a good adjustment would be to have about 4 volts on the filament of the second valve, therefore its grid will be at —4 volts; adjust the H.T. battery volts to best rectifying value and then increase the voltage on the first filament to give a maximum amplification. By this means one L.T. and one H.T. battery will serve for both valves. The condensers of the two tuned circuits can be geared together and adjusted so that

the tuning of the two circuits can be done simultaneously by the movement of one handle.

The Wireless Telegraphy Company in Berlin has recently taken out a patent for a valve receiver circuit, shown in Fig. 27. If this is compared with Round's No. 16 Circuit (Fig. 21) it will be seen that they are identical in principle. In these connections the plate circuit is magnetically coupled to the receiver closed circuit by means of a coil A, whereas in the Round connection it is direct coupled; also here the grid circuit is inductively acted upon by the closed circuit through coil B instead of being joined directly across the aerial inductance. There appears to be nothing to gain by so much inductive coupling, and it certainly suggests a loss of

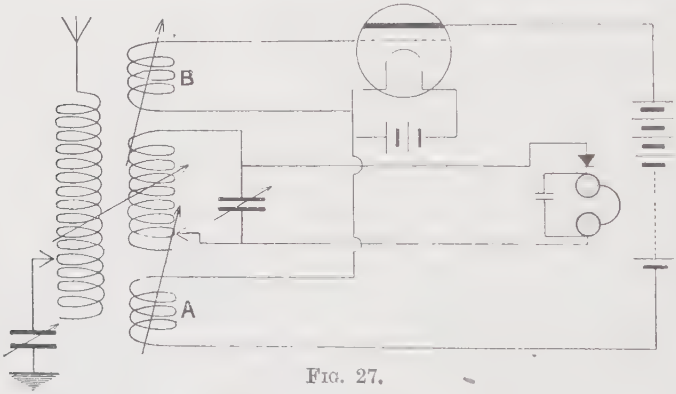


FIG. 27.

efficiency, not only in the resistance of an extra coil but also in magnetic leakage.

For ease of adjustment it is preferable to have the coupling between coil B and the closed circuit fixed, and vary the reaction effects by having a variable coupling only at A. The advantages claimed for this circuit are, first, there is no direct connection between the valve circuit and the receiver circuit, so that beyond the coupling of the coils A and B to the closed circuit inductance an existing crystal receiver can be fitted with a valve without disturbing it in any way; secondly, this method of connection gives greater selectivity than if the grid circuit were directly connected to the receiver closed circuit. The advantage of selectivity would, however, be lost if the coupling of coil B were fixed. The circuit connections above described are the same as those patented by Arco and Meissner in 1914.

Armstrong described a method of amplifying the oscillations by tuning the plate circuit as shown in Fig. 28. The coil L is adjusted to bring the plate circuit into tune with the other circuits, and, as usual, when oscillations of grid potential are produced they cause oscillations in the plate circuit current. From the ordinary laws of induction if the plate current increases suddenly the potential induced in L will oppose the battery potential and *vice versâ.* Thus the potentials induced in coil L, alternately aiding and opposing the battery volts, will cause oscillations in the

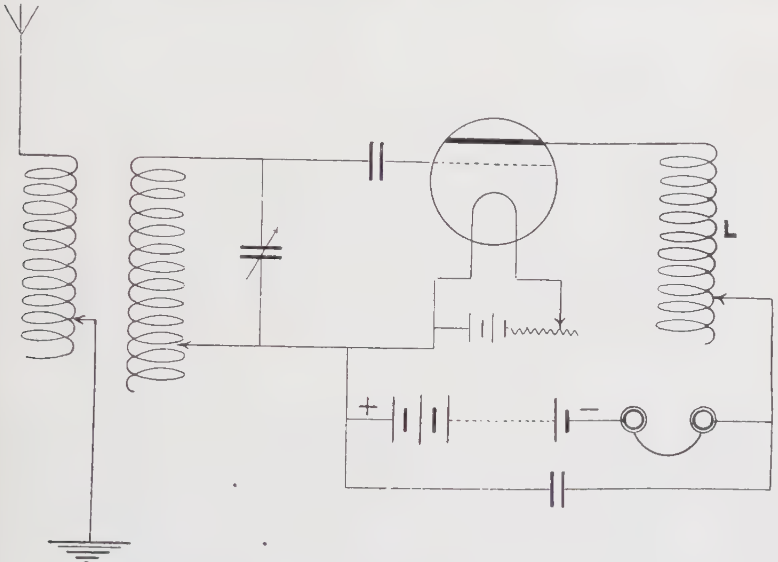


Fig. 28.

potential between the plate and filament and, therefore, oscillations of the grid potential, or an amplification of the effects primarily set up by the ether wave energy. For long wave lengths the coil L may have an adjustable condenser shunted across it.

There is no reason why this method should not be combined with the use of a reaction coil in the plate circuit magnetically coupled to the grid circuit; thus the tuned coil L may be magnetically coupled to the aerial or closed circuit, as shown in Fig. 29, or a combination of coupling and tuning may be adopted, as in Fig. 30.

The circuit shown in Fig. 29 has been tested, and the results have shown that there is a decided advantage in tuning the plate circuit, provided it is done intelligently. From the explanation

given above of the action of coil L it is seen that the condenser C_2 should be kept small in value, while for wave lengths above 600 metres it is desirable not to put all the plate circuit inductance into the reaction coil, but rather to adopt the arrangement shown in Fig. 30.

An interesting circuit, patented by Armstrong in 1914, is shown in Fig. 31. The plate circuit contains a reaction coil R, whose

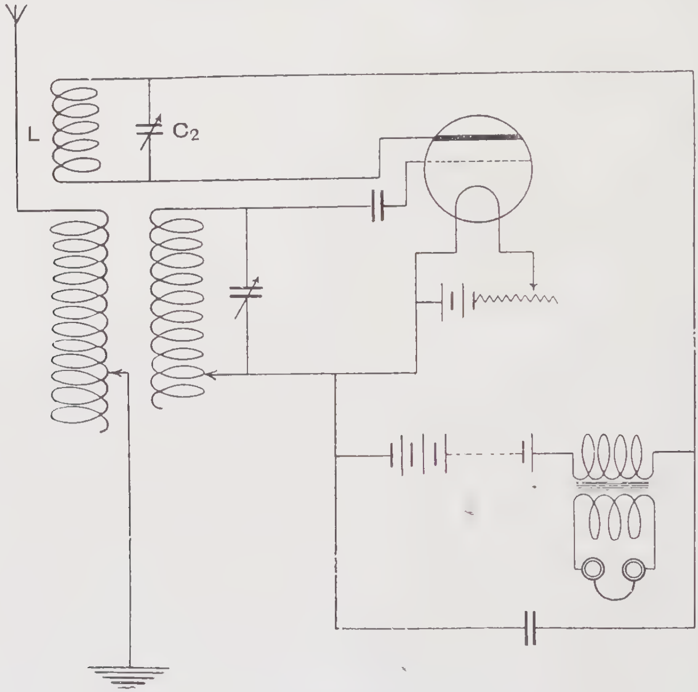


FIG. 29.

effect is similar to that of coil L in Fig. 28. In series with this reaction coil is a variable condenser C_3 shunted by an iron core impedance coil. The plate circuit is coupled to the receiver circuit by the inductance of the telephone receivers with the variable condenser C_2 in shunt across them.

The condenser C_2 is varied until the oscillations generated by the reactions between the valve circuits have a frequency slightly different to that of the receiver circuit and, therefore,

of the transmitted signals. Thus beats of audible frequency are produced and these beats are amplified by the valve and its circuits.

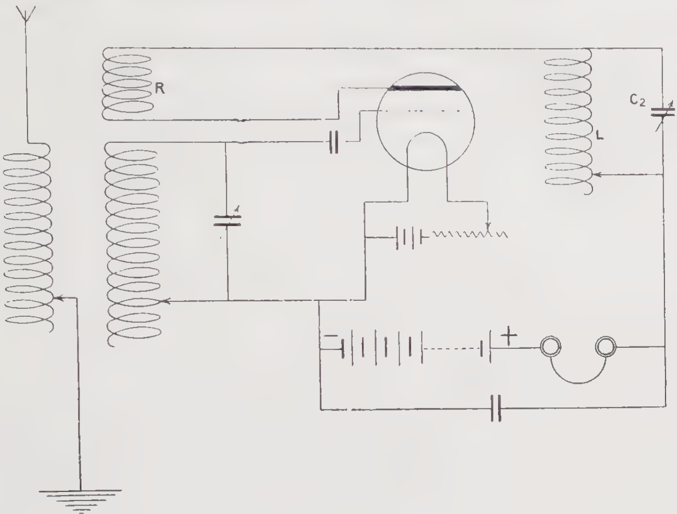


FIG. 30.

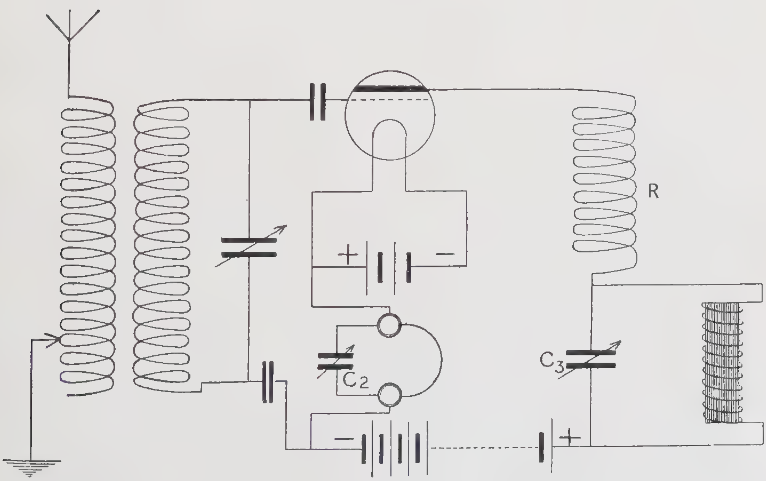


FIG. 31.

This method is applicable to C.W. reception as it heterodynes the signals.

With one valve connected to provide a reaction effect on the receiver circuits it is possible to make signals loud which would be just audible with a crystal detector. For the detection of very weak signals the practice is tending towards the use of two or more valves in cascade rather than a reaction effect from one valve back into the receiver circuits.

We have already seen that, under suitable conditions, high frequency oscillations impressed on the grid potential of a valve will produce on the plate circuit current corresponding high frequency oscillations, together with plate current pulses of low or telephonic frequency. By the use of a reaction coil we can amplify both. The question at once arises—shall we connect the valves in cascade to amplify the high frequency oscillations or the low frequency pulses ?

Let us consider the case of signals which are far too weak to be detected by a crystal. If a valve is used the oscillations of the grid potential will be very small, probably too small to have much effect on the plate current, and it is, therefore, better to try to amplify the oscillations before amplifying pulses which barely exist. After the oscillations have been amplified we can amplify the low frequency pulses, as in Round's double magnification circuit, or with valves in cascade, and get remarkable results as regards strength of signals.

It would appear better, therefore, in the case of very weak signals to connect two valves in cascade in such a way that the first is used simply to amplify the high frequency oscillations. The plate circuit of the first or second of these valves should react back into the receiver circuits, for without this we should have no advantage over the use of one valve with a reaction coil. More than two valves in cascade for this purpose would be unnecessary, and would probably give trouble owing to inter-oscillation between them. Since the first valve would be used for augmenting oscillations it need not rectify, *i.e.* if a French valve its grid should have a negative potential of, say, 5 volts, obtained by means of a potentiometer, not a leaky condenser, so that it works at point B on the curve of Fig. 10. The second valve should have a leaky condenser in series with the grid to give rectification ; if necessary amplification of the low frequency pulses can then be obtained by any of the methods described later.

A circuit by which high frequency oscillations may be amplified with two valves is shown in Fig. 32. The plate circuit of the first valve and the grid circuit of the second valve are

magnetically coupled; and both should be tuned into resonance with the receiver circuit. The capacity effects in C_1 and C_2 should be kept as small as possible, and used only to give fineness of tuning.

One great advantage of this method of amplifying the oscillations with tuned valve circuits in cascade is that very sharp selectivity is obtained. This should be especially valuable for working on a fixed wave length, when the condensers C_1 and C_2 can be set permanently to the best adjustment, otherwise proper tuning will require some skill on the part of the

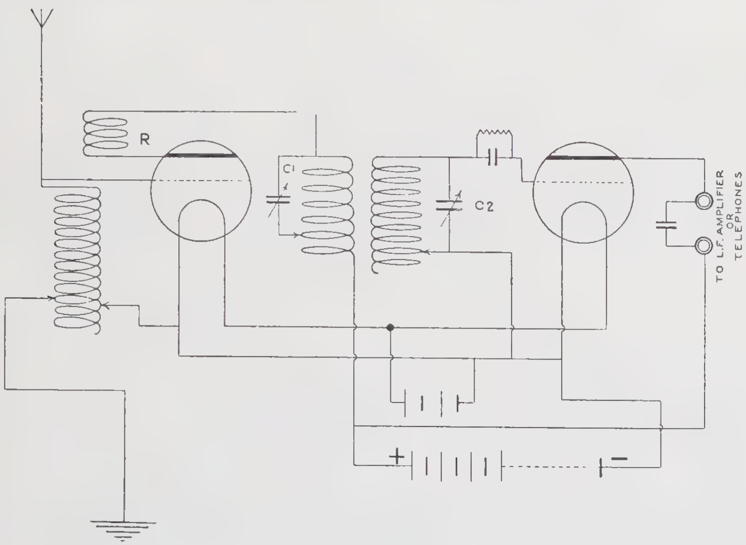


FIG. 32.

operator. A further description of this type of circuit will be given in Chapter VI. in connection with H.F. Amplifiers.

A simple method of double magnification is shown in Fig. 33. Here the coil R acts as a reaction coil, so that amplified oscillations in the plate circuit of the valve react back into the grid circuit, while the low frequency pulses are led back through the valve by means of the iron core transformers. Another circuit proposed by Round, in which two amplifying valves are employed, is shown in Fig. 34. A comparison between this circuit and the connections of the 4-valve amplifier, shown in Fig. 62, will demonstrate that the

same principles are adopted in both cases. Round obtained

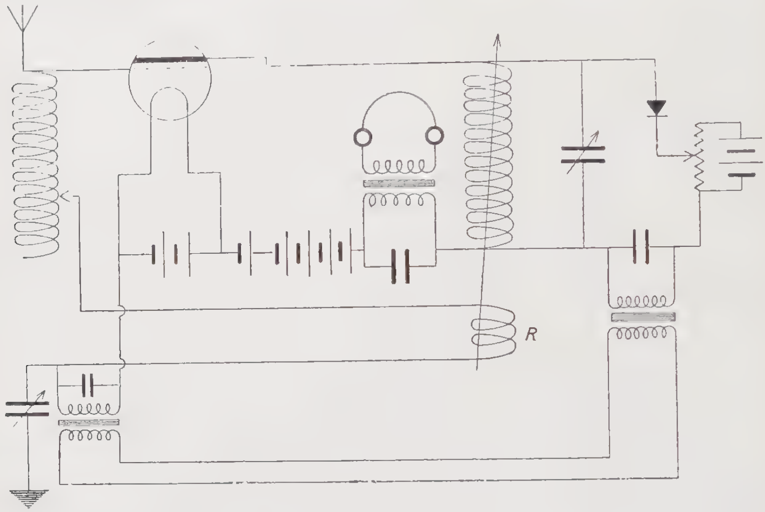


Fig. 33.

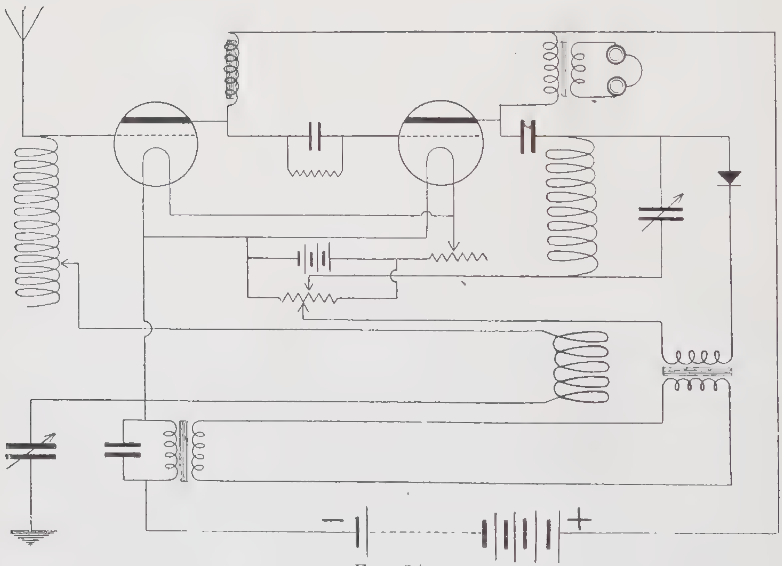


Fig. 34.

good results with a high frequency amplifying arrangement of his

receiver circuit as shown in Fig. 35. The coil S was about 20,000 ohms, wound on an iron core, and the best results were obtained with 150 volts in the plate circuit of the last valve, irrespective of the design of valve used. The first two valves give high frequency amplification, rectification being aided by a proper adjustment of plate voltages.

From time to time various complex amplifying circuits have been proposed, but modern practice is tending towards simplicity of the tuned receiver circuits, the necessary amplification of both high and low frequencies being obtained by special amplifying apparatus behind the receiver. As remarked before, a valve functioning in the region of zero grid potential has very little damping effect on the oscillations; for ordinary purposes a receiver

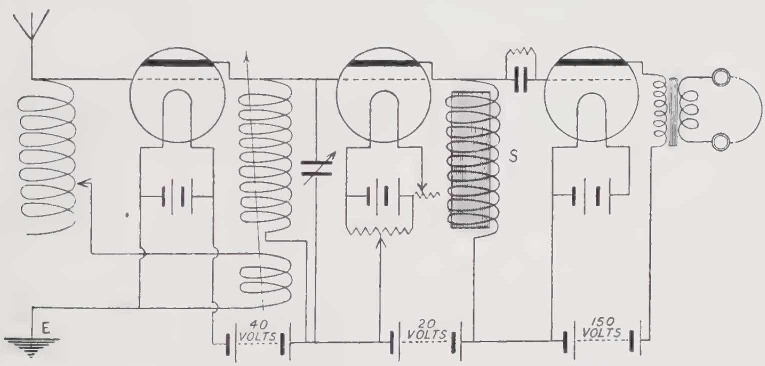


Fig. 35.

with two loose coupled circuits and fitted with a valve reacting back into the aerial circuit will give good amplification and fair selectivity. The receiver circuits should be tuned by inductance steps and the variable condenser across the closed circuit should be as small as possible. If very sharp tuning is required, to avoid jamming, two valves may be coupled in cascade by tunable circuits as in Fig. 32 and this will give an amplification of many hundred-fold. Further amplification can then be obtained by the use of low frequency amplifiers. Instead of two valves in cascade on tunable circuits special high frequency amplifiers may be connected behind the receiver circuits to produce the same results. These instruments will be described in a subsequent chapter, also other valve receiver circuits—specially suitable for the reception of C.W. signals.

QUESTIONS ON CHAPTER IV.

1. Draw a diagram showing how a valve may be used to couple an aerial circuit to a tuned secondary circuit, amplifying the oscillations at the same time without any reaction effect.

2. Explain the respective functions of the valve and the crystal detector in Round's No. 16 Circuit for single magnification.

3. What are the advantages and disadvantages of using one valve for both rectification and oscillation amplification ?

4. If a valve receiver is fitted with a reaction coil how do you know when its coupling effect is properly adjusted for receiving spark signals ?

5. If continuous loud whistling noises are heard in the telephones of a valve receiver what is likely to be the fault in the circuit ?

6. What are the advantages and disadvantages of using valves in cascade coupled by tuned circuits for H.F. amplification ?

7. On a valve receiver it is noted that if the grid series condenser is small and the leak resistance high sharp recurring clicks are heard in the telephone receivers. Give an explanation of this ?

8. On a valve receiver with a grid series condenser of 0·0003 mfd. strong local C.W. signals are improved with a leak value of 1 megohm, but weaker C.W. signals are best with a leak value of 3 megohms. Give an explanation of this.

9. Why does a change of the value of the leak across the series grid condenser in a French valve receiver generally change the wave length range of the latter ?

10. Does the reaction coupling used in a French valve receiver influence the values which should be chosen for the series grid condenser and for its leak resistance ?

CHAPTER V

THE VALVE AS A GENERATOR OF OSCILLATIONS

In the previous chapters it has been shown that oscillations impressed on the grid circuit of a valve will produce corresponding oscillations in the plate circuit current, provided this is arranged to have a low impedance for high frequency currents. These oscillations in the plate circuit current can be made to react back into the oscillating receiver circuits, and thus amplify the oscillations in the latter.

By suitable arrangements a valve can be made to generate oscillations in its own circuits without any influence external to them; the oscillations thus generated will be undamped, and with proper values of potentials and currents they can be used for the transmission of undamped waves, usually called Continuous Wave or C.W. Transmission. Under reception conditions and in amplifiers these valve-generated oscillations are often present; they have been referred to in connection with the receiver of Fig. 24, and we may now consider the conditions under which they are set up.

It may be remarked that Edwin Armstrong's U.S. Patent No. 1113149, dated January 31, 1913, because on that date he had his drawings witnessed before a notary, first discloses the fact that with a certain value of feed back coupling between the plate and grid circuits, a valve would become a high frequency generator. Meissner's German patent of April 9, 1913, showed a feed back circuit for producing oscillations.

Suppose a circuit is made up as in Fig. 36 with a milliammeter (A_1) in the plate circuit and a hot-wire milliammeter (A_2) in series with the variable condenser K_1 across the plate circuit inductance AB.

The valve may be an ordinary French valve, with about 5 volts on the filament and from 300 to 400 volts in the plate circuit. The moment the plate circuit is closed by the key its current is

registered on A_1, and if the portions of the coil AB and BC are of suitable value a current will be registered on A_2. Since a direct current cannot flow through a condenser, the current registered on A_2 must be an oscillating one.

The characteristic curves of the valve for different plate potentials are shown in Fig. 37; with constant filament temperature they will all have the same saturation value except those corresponding to plate potentials which are relatively low.

Let XY be the curve corresponding to the plate potential in use; the grid being normally at zero potential in the connections of Fig. 36. When the circuits of the valve are completed by pressing the key a plate current flows and sets up a magnetic field in the coil AB; this magnetic field induces in AB a voltage

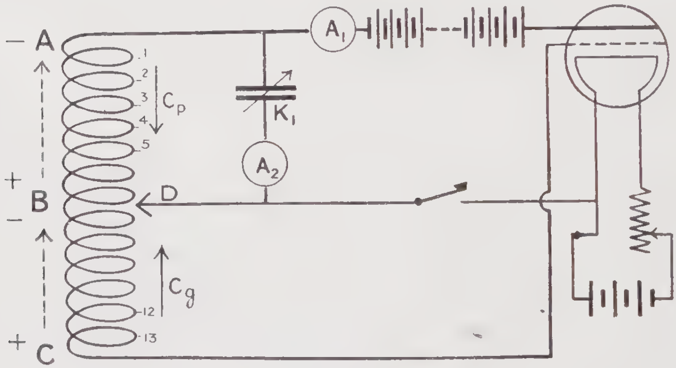


Fig. 36.

acting against the current so that the current does not rise to its normal value (0Z in Fig. 37) instantaneously. The direction of this back E.M.F. of inductance is shown by the dotted arrow in Fig. 36 between A and B, taking the direction of current as the direction of electron flow from plate through AB to filament. The effect is that the plate voltage is not initially that corresponding to the curve XY, but rises from curve to curve, the plate current rising with it and tending to attain the value 0Z. At the same time the magnetic field in AB interlinks with the turns in BC, inducing a voltage in BC in the same direction as that induced in AB. This induced voltage in BC is shown by a dotted arrow and the signs + and – between B and C in Fig. 36. It will be seen that the induced potential in BC makes the grid positive with respect to the filament, and because of this the plate current

rises beyond the value corresponding to 0 grid potential to some value such as Z_1 on the characteristic curve.

Now when the grid is at positive potential with respect to the filament the grid circuit current increases, and the negative flow is in the direction shown by the full-line arrow marked C_g in Fig. 36; it is in the same direction as the induced volts in BC and in the opposite direction to the plate current as far as

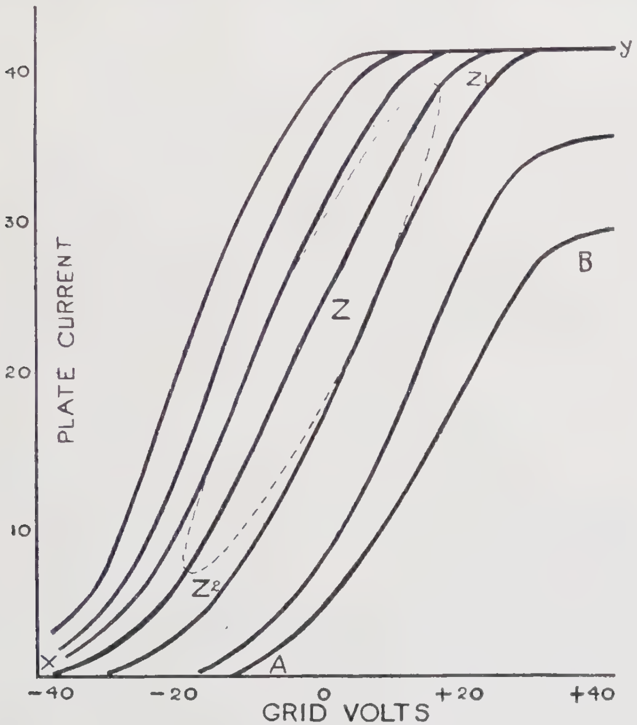


Fig. 37.

the coils are concerned. As it increases this grid current is building up a magnetic field in BC which is in opposition to the magnetic field set up in BC by the plate current, since the two currents are acting in opposition; eventually the result of the two will be that the magnetic field in BC is reduced to zero, so that the induced voltage in BC is wiped out and the grid returns to 0 potential. This tends to make the plate current fall from Z_1 in Fig. 37, but a fall of plate current is accompanied by a

decreasing magnetic field in the coils, and the action of the reversed magnetic field in BC is to induce in it a reversed potential, so that the grid becomes negative with respect to the filament. This pulls down the plate current so that instead of falling from Z_1 to Z it falls to a value Z_2, corresponding to the negative grid potential. Here it is necessary to point out that when the plate current is decreasing the magnetic field in AB will induce a voltage in it acting in the same direction as the battery and not in opposition as with an increasing field. That is to say, during the decrease of plate current the plate circuit voltage will be increased by induction, the increase being a maximum when the current is falling through its normal value; thus, referring to Fig. 37, during the decrease of plate current the action leaves the curve XY, passes successively to higher ones, and returns again.

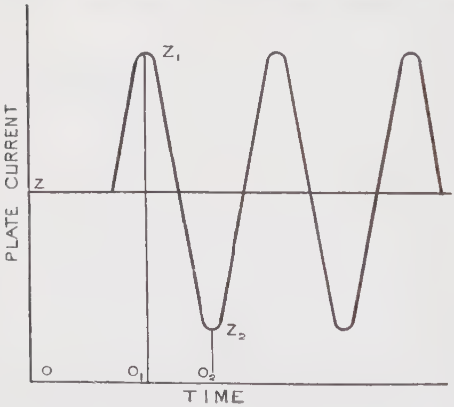


Fig. 38.

When the grid potential is sufficiently negative the grid current is zero or very small, BC has no effective magnetic field of its own, the magnetic field from AB has died down with the decreasing plate current, and the induced voltage in BC dies out so that the grid returns to 0 potential. The plate current has therefore increased again and the whole sequence of events is repeated.

Thus under suitable coupling conditions between the coils AB and BC the plate current does not stay at the steady value 0Z; it pulsates up and down between the values 0_1Z_1 and 0_2Z_2, *i.e.* it is a pulsating current of constant direction, not quite the same as an ordinary alternating or oscillating current.

It is in fact a steady plate current with oscillations superimposed on it; it not only rises to $Z_1$and falls to Z_2, with the oscillations of grid potential, but also moves from one characteristic curve to another, according as the potential induced in the plate circuit at AB acts with or against the plate circuit battery. The instantaneous values of plate current will trace out approximately

an elongated ellipse as shown dotted in Fig. 37. The width of this ellipse will increase as the resistance R of the oscillating circuit increases; it will also depend on the plate coil current and vary inversely as the resistance of the plate circuit in the valve. In practice the plate potential will be relatively high and the characteristic curves almost vertical, so that if the values of plate current are plotted against time they will swing above and below the mean value of plate current, with an oscillating amplitude as shown in Fig. 38: the ammeter A_1 will read the effective value of the current in the circuit.

We have seen that the oscillations in the value of the plate current induce in the coil AB a voltage which rises and falls and reverses in direction; thus between the points AB an oscillating potential is set up. If we apply this oscillating potential to a circuit, such as the condenser K_1 in series with the ammeter A_2, an oscillating current will flow in this circuit; its value will depend directly on the voltage in AB and inversely on the impedance of the circuit $K_1—A_2$. The effective value of this current may be 200 milliamperes when the effective value of plate circuit current as read on A_1 is only 20 milliamperes.

Now the oscillations on the plate current would tend to decrease owing to the damping effect of the resistance in the plate circuit, just an an ordinary oscillating pendulum will come to rest owing to friction loss in its bearings. But with sufficient mutual induction in the coupling of the coils in the plate and grid circuits we see that at each half oscillation, when the grid is at positive potential, the grid current increases rapidly accompanied by an increased current in the plate circuit. At each half oscillation the mutual induction, acting on the grid potential, introduces a negative resistance effect into the plate current circuit, allowing an extra pulse of current to flow from the plate circuit battery. This extra pulse of energy from the battery makes up for ohmic loss and sustains the oscillations; it corresponds to an escapement spring fitted to a pendulum which gives to the latter a new pulse of energy, making up for that lost in friction and keeping the pendulum in continuous oscillation.

Therefore it is evident that undamped oscillations of the potential across AB will be generated by the valve only when there is a suitable mutual inductance effect between the plate and grid circuits. It must be a negative mutual inductance, the grid field opposing the plate field, and it must be of sufficient value to just more than overcome the damping effects on the oscillations of the plate current.

In practice this implies that there must be a definite relative number of turns in both the plate and grid circuit coils; it will not do to have a small number of turns in either of them. The results of an experiment will make this clear; a circuit was made up as in Fig. 36, the coil having 13 tappings and a total inductance of about 800,000 cms.; the condenser K_1 was set at 0·0003 mfd., and the volts in the filament and plate circuits were 6 and 200 respectively. The plate current and the oscillating current through K_1 were read as the contact D was moved from stud to stud, the results being as shown in the Table.

Stud.	Plate current (milliamps.).	Oscillating current in K_1 (milliamperes).
1	13	0
2	37	30
3	37	43
4	31	64
5	21	64
6	13·5	64
7	13	58
8	13	46
9	15	0
10	15	0
11	15	0
12	15	0
13	15	0

It is necessary to remark that with 200 volts on the plate the point on the characteristic curve corresponding to zero grid potential is not at the centre but below it. Thus when the contact was on stud 2 the grid potential made large swings, because the coil BC had a large number of turns; the plate current rose high up the curve but could not fall much since it soon reached the lower bend of the curve where the plate current becomes zero. Therefore the pulsations upwards are greater than those downwards and whilst oscillating the effective value of the plate current rises from 13 to 37 milliamperes, owing to the partial rectification upwards of its oscillating component. At the same time the coil AB has a small number of turns, the oscillating potential induced across it is small, and therefore the oscillating current which it sends through the condenser is only 30 milliamperes.

When the 6th stud is used the swings of grid potential are not so great, since the coil BC has now a less number of turns, the plate current oscillations upwards are not so great, and are of

about the same amplitude as the oscillations downwards, so that the effective value of plate current is nearly the same as when not oscillating. But the plate coil AB has now more turns and the induced voltage in it is greater than before, so that an oscillating current of 64 milliamperes flows through the condenser. When the grid coil is too small, as when the 9th or a higher stud is used, the oscillations of the plate current, and of the potential across AB, are not sufficiently great to provide a perceptible oscillating current through the condenser K_1.

Instead of having one coil, with tappings from it to the plate and grid, separate coils suitably coupled may be employed for

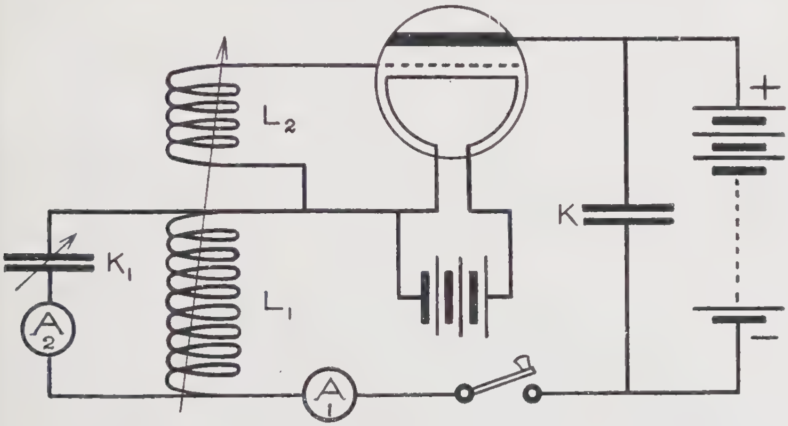


FIG. 39.

the two circuits; one coil may slide inside the other or its axis may be made adjustable with respect to that of the other. The connections would then be as shown in Fig. 39. It is usual to shunt the battery with a blocking condenser as shown at K so that the oscillating component of plate current may have a low impedance path through this portion of its circuit. With two separate coils due regard must be paid to the sign of the mutual induction, which must be negative. If, for example, the coil L_2 is turned the wrong way round with respect to L_1 oscillations will not be sustained except in very special cases.

Now let us consider more definitely the conditions under which the valve will generate oscillations; for sustained oscillations the grid potential must oscillate, and its oscillations must be sustained against the ohmic, or CR, drop of volts in the circuit by having a

voltage induced periodically in the coil L_2 by the pulses of current in L_1. The voltage induced in L_2 will depend on the mutual induction between L_1 and L_2, it will also depend on the frequency of the pulses in L_1 and the strength of these pulses. The frequency will depend on the values of L_1 and K_1; for example if K_1 is increased the frequency is lowered and the mutual induction or coupling between L_1 and L_2 must be increased to keep up the induced voltage in L_2. The pulses, or oscillations, of current in L_1 will depend on the resistance of the coil L_1 and of the plate circuit, the latter being determined by the filament temperature.

It is thus evident that the mutual induction, required from the plate to the grid circuit to sustain oscillations, will depend in some way on the values of L_1 and K_1 on the resistance of coil, L_1, and on the resistance between the plate and filament in the valve.

The following solution is due to Professor C. Gutton of the Faculty of Science at Nancy. The equation of the characteristic curve of a French valve can be written :—

$$rC_p = V_p + FV_g - x$$

where r is the plate-filament resistance, C_p the plate current, V_p and V_g the plate and grid potentials with respect to the filament. F the voltage amplifying factor, and x a constant if the filament temperature is constant. It will be assumed that the direction of the currents is the positive direction, *i.e.* opposite to that of the electron flow.

When the valve is oscillating the plate current has a steady value component C_p plus an oscillating component C_{p1}; similarly the plate voltage has a steady component V_p (the voltage of the battery) plus an oscillating component V_{p_1}, and the grid potential has a steady value V_g (which may be zero as in Fig. 39) plus an oscillating component V_{g_1}. The equation is then :—

$$r(C_p+C_{p_1})=(V_p + V_{p_1}) + F(V_g + V_{g_1}) - x$$

By subtraction between these two equations we obtain :—

$$rC_{p_1} = V_{p_1} + FV_{g_1}$$

If i_c is the current in the plate coil, and R the resistance of the coil, the oscillating voltage induced in it, V_{p_1}, is $-\left(Ri_c + L_1\dfrac{di_c}{dt}\right)$ and

the oscillating voltage induced in L_2 is $-M\frac{di_c}{dt}$; thus –

$$rC_{p_1} = -\left(Ri_c + L_1\frac{di}{dt}\right) - FM\frac{di_c}{dt}$$

The current in the condenser K_1 is $K_1\frac{dV_{p_1}}{dt}$; the vectorial sum of this and the current in L_1 must equal the oscillating component of current in the plate circuit, *i.e.* $C_{p_1} = i_c - K\frac{dV_{p_1}}{dt}$. Thus :—

$$r\left(i_c - K\frac{dV_{p_1}}{dt}\right) = -\left(Ri_c + L\frac{di_c}{dt}\right) - FM\frac{di_c}{dt}$$

By eliminating V_{p_1} this gives a differential equation for i_c, the oscillating current in the plate coil L, of the form :—

$$A\frac{d^2i_c}{dt_2} + B\frac{di_c}{dt} + Ci_c = 0$$

From this it can be shown [1] that if $R + \frac{L + FM}{Kr} > 0$ the first pulse of current in the plate circuit will not be sustained, and the plate current will settle down to a steady value, *i.e.* Cp_1 becomes zero. $R + \frac{L + FM}{Kr}$ must be >0 if M is positive since all the other terms are positive; or when M is negative if it is less than $\frac{I}{F}(L + KrR)$. On the other hand, the oscillations will be sustained if $R + \frac{L + FM}{Kr} < 0$; since R and L are positive *this can only happen if M is negative and if* $-M$ *is greater than* $\frac{1}{F}(L + KrR)$.

The amplifying factor in volts, F, depends on the voltages applied; thus it is seen that the mutual induction, or degree of coupling, required between the plate and grid circuits depends on the characteristic curve on which the valve is functioning, and on L, K, and R, as pointed out above.

The values of the various oscillating currents and voltages can be deduced; for this purpose let $\omega = 2\pi f$ and I_c represent the effective value of the oscillating component of current in the

[1] See note at end of chapter.

plate circuit coil L_1; the instantaneous effective values will be as follows:—

(1) The oscillating current in the plate circuit coil L_1

$$= i_c = I_c \sin \omega t$$

(2) The oscillating potential of the grid:—

$$V_{g_1} = -M\frac{di_c}{dt} = -M\omega I_c \sin\left(\omega t + \frac{\pi}{2}\right)$$

(3) The oscillating potential of the plate when R is the resistance of the coil L_1 is:—

$$V_{p_1} = -Ri_c - L_1\frac{di_c}{dt} = -RI_c \sin \omega t - \omega L_1 I_c \cos \omega t$$

$$= I_c\sqrt{R^2 + \omega^2 L_1^2} \times \sin\left(\omega t - \frac{\pi}{2} - \theta\right)$$

where $\tan \theta = \dfrac{R}{\omega L_1}$.

(4) The oscillating current in the plate circuit:—

$$C_{p_1} = \frac{-R}{r}i_c - \frac{L_1 + FM}{r}\cdot\frac{di_c}{dt}$$

$$= \frac{-R}{r}I_c \sin \omega t - \frac{L_1 + FM}{r}\omega I_c \cos \omega t$$

$$= \frac{-I_c}{r}\sqrt{R^2 + \omega^2(L_1 + FM)^2} \times \sin\left(\omega t + \frac{\pi}{2} + \beta\right)$$

where $\tan \beta = \dfrac{R}{-\omega(L_1 + FM)}$ and is >0.

(5) The oscillating current in the condenser K_1:—

$$i_K = -K\frac{dv_{p_1}}{dt}$$

$$= -K\frac{d\left\{-I_c\sqrt{R^2 + \omega^2 L^2} \times \sin\left(\omega t - \frac{\pi}{2} - \theta\right)\right\}}{dt}$$

$$= -KI_c\sqrt{R^2 + \omega^2 L^2} \times \omega \cos\left(\omega t - \frac{\pi}{2} - \theta\right)$$

$$= -KI_c\sqrt{R^2 + \omega^2 L^2} \times \omega \sin(\omega t + \pi - \theta)$$

In practice, when R is very small compared with $2\pi f L_1$ and $\dfrac{1}{2\pi f K_1}$, and when at the limit of oscillations $2\pi f L_1 = \dfrac{1}{2\pi f K_1}$, the

currents in the plate coil L_1 and the condenser K_1 are nearly equal.

(6) The oscillations of the potentials of the plate and grid circuits give a resultant which sustains the oscillations, and Prof. Gutton calls this the *oscillation electromotive force*. When the coupling is set for the limit of oscillations this must be in phase with the current in the plate circuit coil, since the circuit is then in resonance.

Phase Relations in the Plate and Grid Circuits.—With an increasing plate current a grid potential is induced in the positive direction and at the same time a back E.M.F. is induced in the plate circuit; thus it is evident that the plate potential decreases when that of the grid increases, and therefore that the oscillating potentials in these two circuits are either exactly or nearly in opposition. Referring to the values of V_{g_1} and V_p previously given in (2) and (3) it will be seen that their phases are more than 180° apart by a small angle θ, where $\tan\theta = \dfrac{R}{2\pi f L_1}$. The oscillating current i_c in the plate coil must be 90° behind the grid potential V_{g_1}, and therefore $(90 + \theta)°$ in front of the oscillating voltage induced in the plate circuit coil, or 90° in front of the component $-2\pi f L_1 i_c$ of this voltage.

This is shown by the vector diagram in Fig. 40 (*a*), where OA is the induced volts V_{p_1} in the plate circuit and OB the induced volts V_{g_1} in the grid circuit. The plate voltage OA has two components; one OC is in opposition to the induced grid voltage and equivalent to it, taking into account the ratio of transformation of the two circuits; the other OD sustains the oscillating current which is built up in the plate coil. The oscillating potential V_{p_1} in the plate circuit is applied at the terminals of the coil L_1 to the condenser K_1; the resulting current i_k into the condenser is at right angles to V_{p_1}; compare the previously given formulæ (3) and (5). The circuit L_1K_1 is nearly in resonance when R is very small, therefore the condenser current is nearly equal to the coil current and in phase with it as far as this oscillating circuit is concerned. But as regards the plate circuit the condenser and coil currents are of opposite sign at any instant; therefore the resulting oscillating current C_p in the plate circuit is as shown at OF. It is seen that the oscillating component of plate current is a little more than 90° in front of the current i_c oscillating in the plate circuit coil L_1; it also leads the grid potential by an angle β. Since $\beta = \tan^{-1} - \dfrac{R}{\omega(L + FM)}$ the effect of increasing the

resistance is apparent. It may be noted that the current oscillated in the condenser I_k can be very much greater than the oscillating component of plate current C_{p_1}. In C.W. transmission, where the

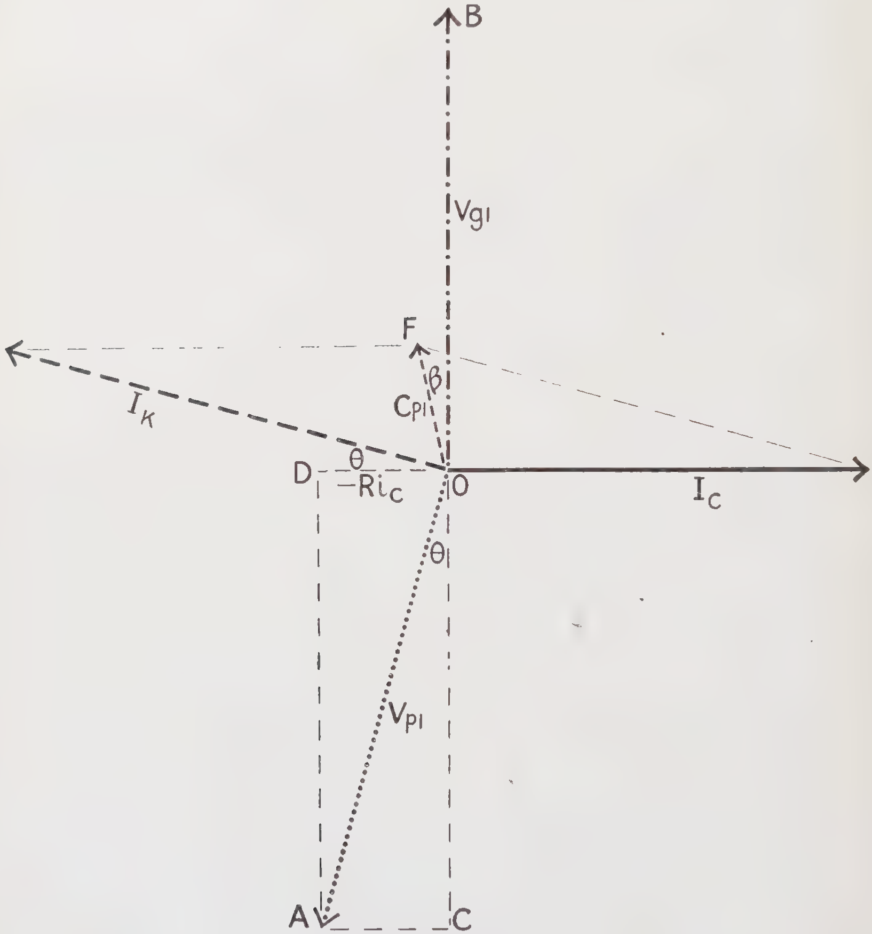


FIG. 40 (a).

plate current may oscillate from zero to saturation values and the condenser is replaced by an aerial circuit, the plate current may have an effective value of 20 or 30 milliamps. when the aerial current is 200 milliamps.

The phase relationship of the different oscillating potentials and currents in a valve are again shown by the curves in Fig. 40 (*b*).

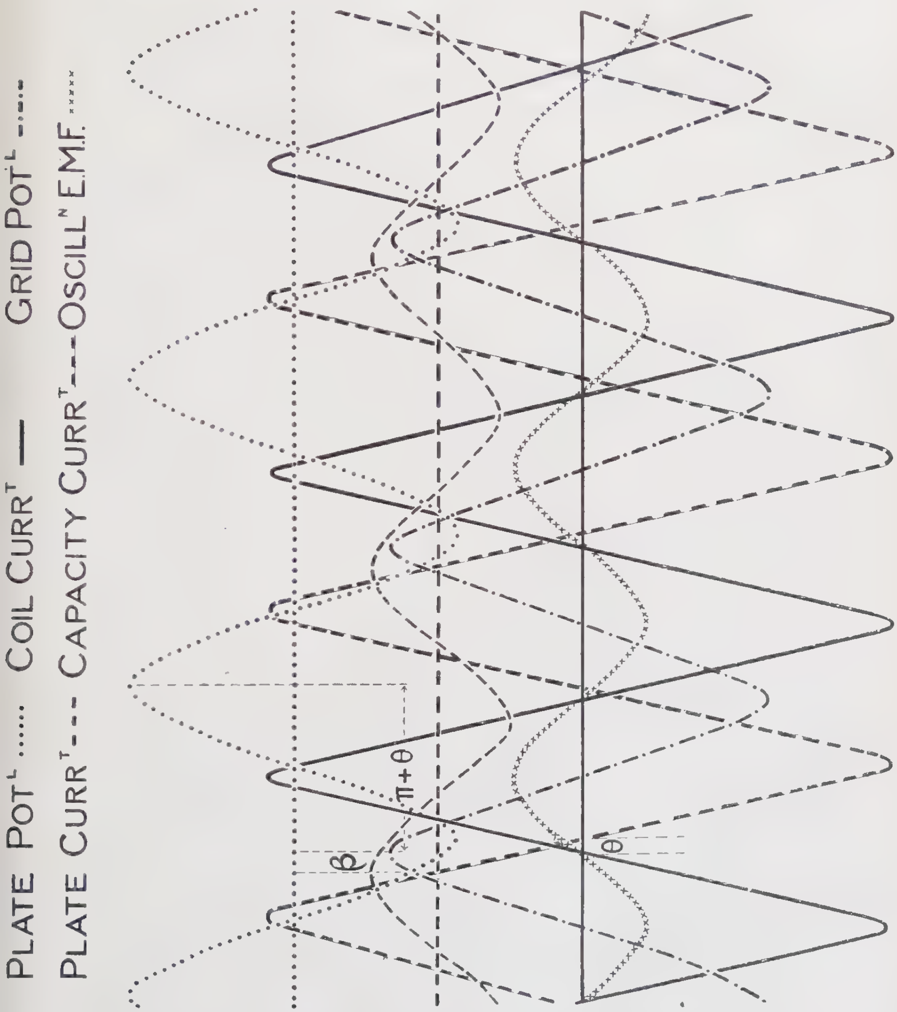


FIG. 40 (*b*).

It may be noted here that if the condenser circuit contains a resistance, as it would do if the condenser is replaced by an aerial circuit, the condenser current is reduced in value, and brought more nearly into opposition of phase to the coil current. This

reduces the oscillating plate current, and with too much resistance oscillations will not be sustained unless the coupling is tightened.

It is interesting to compare these calculations with those derived by G. Vallauri (see *The Electrician* for December 21, 1917). Vallauri deals with the Audion valve and states the equation of the plate current as :—

$$C_p = av_g + bv_p + C$$

Thus $\frac{1}{b}$ is the resistance r between the plate and filament in the valve, $\frac{a}{b}$ is the voltage amplifying factor F, and $\frac{1}{a}$ is equal to $\frac{r}{F}$.

With an oscillating circuit of inductance L, capacity K, and resistance R included in the plate circuit of the valve, where R′ is the resistance of the remainder of the plate circuit, Vallauri finds the limit of oscillations to be given by the equation :—

$$M = -\frac{bL + (1 + bR')RK}{a}$$

This can be written $M = -\frac{b}{a}L + \frac{1}{a}RK + \frac{b}{a}R'RK$

$$= -\frac{L}{F} + \frac{rRK}{F} + \frac{R'RK}{F}$$

$$= -\frac{1}{F}(L + rRK + R'RK)$$

If therefore R′ is very small, as was assumed in the previous calculation, this formula is in agreement with that deduced by Prof. Gutton. It was also stated by Vallauri that the plate current and grid potential are in phase, and in opposition of phase to the plate potential ; that the oscillations are more easily set up the greater is a and the smaller is b, *i.e.* the greater the voltage amplifying factor F ; that the oscillations are more easily set up the more rapidly the plate potential varies with the grid current; finally that they are more easily set up the smaller the decrement and the greater the frequency. This is all more or less in agreement with the conditions already obtained and set out above.

If negative potential is put on the grid the valve functions low down on the plate current curve, and when not oscillating the steady value of the plate current is small.

Referring to Fig. 41, if AB is the plate current characteristic

under the given conditions of potential and $-x$ is the negative potential on the grid, the plate current when not oscillating is xy. When oscillating under suitable conditions of coupling the plate current can oscillate up to saturation and down to zero; it is seen that this gives partially rectified oscillations, and when oscillating the effective value of plate current rises to the dotted line shown in the Fig., or as read on the plate circuit ammeter A_1 of Fig. 39. The advantages of putting negative potential on the grid are: firstly it limits the grid current; with the valve functioning at zero grid potential the grid current when oscillating may have an effective value which will overload the grid and damage the valve; starting from negative grid potential the grid current never swings to a high value. Secondly (for weak oscillations in which the plate current does not rise to saturation value), the effective value of the plate current when oscillating is generally less than if the valve were functioning at zero grid potential, and yet the oscillating current in the shunt condenser is generally greater owing to decrease of grid current reaction. Thus, on the whole, the valve is not so heavily worked, and the generation is more efficient with less load on the source of potential for the plate circuit.

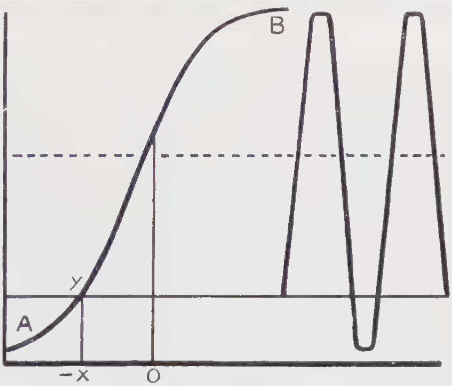


FIG. 41.

Whatever may be the initial grid potential the oscillations of plate current are due to the swings of this grid potential, and the mutual induction should be so loose that the oscillations are built up to the extreme saturation value of plate current. This means that the mutual induction $-M$ should be very little greater than $\frac{1}{F}(L + KrR)$, especially if the valve is functioning near the centre of the plate current curve.

Another interesting effect must be noted here; if the variable condenser K_1 in Fig. 39 is increased, from a small value upwards, it will be found that the oscillating current through it rises at first and then after a certain capacity value is passed it falls; and

at a certain further value it suddenly reduces to zero. The initial rise with increasing capacity can be explained by the fact that as the capacity is increased its reactance is diminished since the reactance of a condenser in ohms is $\frac{1}{2\pi f K}$. But after a certain value of capacity is reached its effect on the frequency must be considered. An increase of capacity decreases the frequency of the oscillations, which is approximately $\frac{5 \times 10^6}{\sqrt{LK}}$, therefore it decreases the induction of potential in the plate circuit coil and the current falls off in the condenser connected across the coil. If the condenser value is made too great $-M$ will not be greater than $\frac{1}{F}(L + KrR)$, and the valve ceases to oscillate.

Prof. Gutton has presented another explanation; the oscillations will be a maximum if the circuits and coupling are so designed that the positive swing of grid potential swings the plate current up to saturation. This takes for granted that the saturation current is the same for different plate potentials. But, referring to Fig. 37, it may be noted that when the grid swings to positive potential, with rising plate current, the plate potential may get on to a characteristic curve such as AB, where the saturation bend to which the plate current can rise is less than the maximum. Prof. Gutton pointed out that when the oscillating maximum is limited by consideration of plate potential its value increases as K increases, but when the oscillations are limited by the plate current swinging up to full saturation value the oscillating maximum decreases as K increases. It is really a question of choosing suitable values for L, K, and R in the plate circuit so that the oscillating maximum may be the same whether it is limited by the swings of plate current or of plate potential. If the self-induction is large and the capacity small, the oscillating maximum is limited by a fall of plate potential at the positive half oscillation; if the capacity is large and the inductance small the maximum is limited by the saturation value of the plate current.

At the limit of oscillations, when $-M = \frac{L + KrR}{F}$ the frequency, $f = \frac{1}{2\pi\sqrt{LK}}$ in absolute measure. By substitution we get $-M = \frac{L}{F}\left(1 + \frac{rR}{(2\pi f L)^2}\right)$, or $= \frac{K}{F}\left(\frac{1}{(2\pi f K)^2} + rR\right)$.

Since the reactance of inductance ($2\pi f\mathrm{L}$) is small compared to $r\mathrm{R}$, and $\dfrac{1}{(2\pi f\mathrm{K})^2}$ is small, we see that an increase of L or K will mean an increase of $-\mathrm{M}$ if the limiting conditions of oscillations are to be maintained.

To sum up it is seen that if L or K are increased in order to decrease the frequency, or increase the wave length of radiation, the mutual induction coupling must be increased; the lower the filament temperature, *i.e.* the greater the valve plate circuit resistance, the tighter must be the coupling; as the resistance R of the plate external circuit increases the smaller will be the

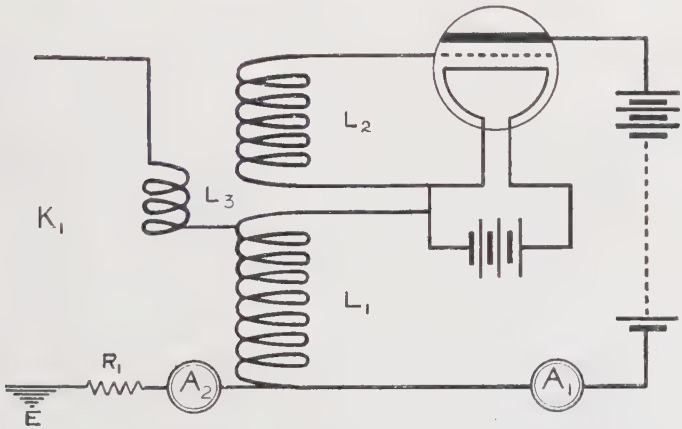


FIG. 42.

capacity which with a given coil and coupling will sustain oscillations.

Let us now consider what will happen if we replace the condenser across the plate circuit coil by an open condenser such as an aerial circuit. These conditions are shown in Fig. 42. The aerial will have some inductance external to the plate circuit coil L_1 and represented by L_3; it may be the inductance of the aerial itself, or of an added coil. There will also be resistance in the aerial circuit, which is represented by R_1. For this case Prof. Gutton shows, by a proof similar to the one already given, that the condition for oscillations is: $-\mathrm{M} > \dfrac{1}{\mathrm{F}}\left(\mathrm{L}_1 + \mathrm{K}r\mathrm{R}\dfrac{\mathrm{L}_1 + \mathrm{L}_3}{\mathrm{L}_1}\right)$. If the aerial is small and L_3 small this is practically the same condition as

before. The aerial current as registered in A_2 will greatly decrease with increase of the resistance R_1; it is therefore very necessary to have a good clean earthing arrangement. From the above formula it is also seen that as the aerial resistance is increased the coupling between the plate and grid circuits must be increased to sustain the oscillations; this will make the frequency and wave length change in value. The frequency is now—

$$\frac{1}{2\pi\sqrt{K(L_1 + L_3) + \frac{R}{Kr}(L_1 + FM)}}$$

and only when R is small compared to r can this be written—

$$\frac{1}{2\pi\sqrt{K(L_1 + L_3)}}$$

It has already been pointed out that if the inductance L_1 in the plate circuit is large compared with the capacity across it the maximum of oscillating energy is smaller than it otherwise would be; it is controlled by the drop of saturation current value owing to the large induction of back potential in the plate circuit, when the grid volts and plate current are increasing. This would happen if a comparatively large coil is employed to get oscillations at a long wave length when using a short aerial, as in the case of certain military C.W. transmitters.

As shown in Fig. 42, it is not necessary to include all the inductance of the oscillating circuit in the plate circuit of the valve; indeed when the capacity is small and the inductance large it is better to limit the plate potential oscillations by reducing the inductance of L_1 and, if necessary, increasing L_3. Thus L_1 and L_3 may both be included in one coil with plug and socket, or movable, contacts so that a suitable portion may be tapped off for connection in the plate circuit. By this means it will be possible to choose the value of plate circuit inductance which gives maximum oscillating current in the plate circuit, and therefore maximum oscillating energy. This adjustment on the oscillating circuit is generally known as the *anode tap.*

Frequency and Wave Length.—The frequency will be a little less than that given by the usual formula $\frac{5 \times 10^6}{\sqrt{(L_1 + L_3)K}}$, and the wave length will be a little longer than $59{\cdot}6\sqrt{(L_1 + L_3)K}$, the

discrepancy increasing with the tightness of the coupling. For good building up of oscillations the coupling should be near the limiting value $M = \frac{1}{F}\left(L_1 + KrR\frac{L_1 + L_3}{L}\right)$, so that for all practical purposes one can calculate the wave length in the usual manner. A formula for the frequency in the general case is deduced at the end of this chapter. It may be noted that if $R + \frac{1}{Kr}(L + FM)$ is not very small, and the valve is oscillating strongly, the frequency is decreased and the wave length is greater than that of the oscillating plate circuit alone.

Also it may be noted that a decrease of filament temperature will necessitate an increase of the mutual induction, M, in order to keep up the oscillations. This will increase the wave length. Where an anode tap is employed as described above a peculiar effect may take place if the capacity across the coil is very small; as when a small aerial is connected to a comparatively large coil to radiate on long wave lengths. If a portion only of the coil is connected to the plate the grid circuit coil will have to be comparatively large to give the necessary value of mutual induction which will sustain the oscillations. This increases not only the inductance in the grid circuit but also its capacity, and the capacity of coil added to the capacity of the valve may make the total grid circuit capacity preponderate over that in the plate circuit. In this case the valve would tend to oscillate at the frequency of the grid circuit; it may in fact become unstable – at one moment oscillating at the frequency and wave length corresponding to the plate circuit, and then by a slight change of coupling or anode tapping it may be suddenly changed to the frequency and wave length of the grid circuit.

This question of preponderating capacity effect will be further dealt with in the chapter on C.W. Transmission; it will suffice to say here that an anode tap may be usefully employed to increase the oscillating power and oscillating aerial current, but it can only be efficiently employed if the aerial capacity across the plate circuit preponderates over the capacities of the coils and valve.

The Oscillating Energy.—The energy oscillated may be obtained by considering its value in the plate circuit coil. If R is the resistance of this coil and $i_{c\ \mathrm{eff.}}$ the current, the energy is then $Ri_c{}^2{}_{\mathrm{eff.}}$. This oscillating energy is supplied by the plate circuit battery, and is abstracted from the energy which would

go to the valve if the latter were not oscillating. This is shown by the fact that a valve is not so bright when oscillating as it is when not oscillating, and it may occur that the plate of a non-oscillating valve becomes red-hot whereas if oscillating it remains dark. It can be shown that the maximum oscillating energy obtainable is half the steady energy applied to the plate circuit under the given conditions of applied potentials when the valve circuits are not oscillating. This maximum can only be obtained if the inductance included in the plate circuit is of such a value that the oscillating plate potential does not decrease the normal value of saturation current. The oscillating energy will be less the greater is the ratio of capacity to inductance in the plate circuit.

Coupling by Means of a Condenser.—Instead of coupling the grid and plate coils the circuits may be coupled by means of a small condenser, as at k in Fig. 43. It is seen that when the plate current is started the induced pulse of potential in L_1 will pulse the potential across k, and cause a pulse of current to flow through k and L_2. This will pulse the grid potential which will, as before, modify the plate current value. With a suitable value of k oscillations will thus be sustained in the circuits. If i is the current in L_2 the potential of the grid is $L_2\frac{di}{dt}$; this should be at an angle of nearly 180° behind the potential of the plate, and i is then 90° behind the potential of the plate. To ensure this the circuit L_2k should not be in resonance with the plate circuit but below resonance.

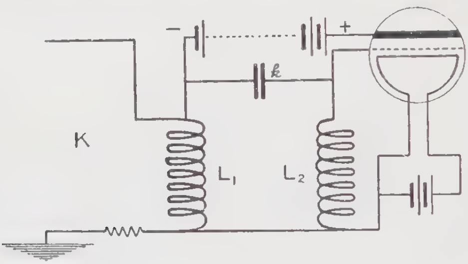


FIG. 43.

Experiment shows that there is a minimum limiting value of the condenser k which will sustain oscillations ; this value increases as the wave length increases, as the resistance of the oscillating circuit on the plate increases, or as the resistance in the valve between the plate and filament is increased by lowering the filament temperature.

Again there is a limiting maximum value of the capacity coupling, for it must be such that the grid circuit is below resonance. Thus it is most convenient to make the capacity coupling by

means of a variable condenser; as far as the grid circuit tuning is concerned it will act in parallel with the existing capacity effect in the valve, and in shunt to the grid coil, therefore its maximum value need not be very great. For wave lengths up to 2000 metres the maximum value of the variable condenser may be about 0·0002 mfd.

It must not be forgotten that this condenser will modify the frequency and wave length of the oscillating circuit on the plate; to a certain extent, therefore, its adjustment can be varied to give fineness of tuning. It is best, however, to keep the coupling condenser as small as possible compared with the grid circuit inductance. From Figs. 39 and 40 it is seen that the oscillating current in the plate coil L_1 divides between, or is the resultant of, the oscillating current in the aerial, or other condenser K, and that in the grid circuit through k. Since it is desirable to have the current in K as large as possible the component through k should be kept as small as possible; the impedance, $\frac{1}{2\pi fk}$, of k should therefore be kept large by giving k a small value. The grid coil L_2 should be sufficiently large to give the necessary induction effect on the grid potential with a small current in it. It is possible, and even desirable, that the coil L_2 should be such that the capacity of the valve itself is sufficient to sustain the oscillations.

A coupling by mutual induction between the coils L_1 and L_2 can be arranged at the same time as a condenser coupling; indeed in the general case where an induction coupling is relied on to give oscillations there is always a certain amount of capacity coupling present, owing to the capacity of the valve and the capacities of the coupling coils. Where induction coupling is relied upon to provide oscillations it may often happen that the valve continues to oscillate even when the coils are drawn far apart, and the mutual induction between them is zero. This is especially the case when the self-induction of the plate circuit is very high and the capacity small; the capacity effects of the large coils and of the valve are then sufficient to sustain oscillations. When the capacity connected across the plate coil is very small, as it would be in the case of a small aerial being employed in Fig. 39, the capacity effect of the valve becomes important in the conditions of oscillations.

Again, cases have been observed where the valve circuits, coupled by mutual induction, sustained oscillations even when the

mutual induction was made positive instead of negative. This was due to the fact that the capacity of the coils and valve provided a coupling sufficient to sustain oscillations. Cylindrical coils made fairly close fitting, with one sliding inside the other, are very liable to give this effect when closely coupled.

With both induction and capacity coupling the oscillations will be sustained, and the capacity coupling will help that of induction, if the capacity reaction is greater than the induction reaction, *i.e.* if $\frac{1}{2\pi fk} > 2\pi f(L_2 \pm M)$. Where M is negative k can be very small, where M is positive an increase of k can satisfy the condition.

This at once suggests that the coils should be designed so that their self-capacities are as small as possible and that the self-periods of the coils should be kept low compared with that which it is desired to sustain in the oscillations. But for short wave work it may well arise that the capacity effects of the coils and valve prevent us from obtaining oscillations of sufficiently high frequency, in which case the coils may be arranged for positive mutual induction and the capacity effect relied on to sustain the oscillations.

In a valve oscillator the frequency will be a little less than that obtained by taking the usual constant of the circuit, $\sqrt{K_2L_2}$, since the capacity effect of the valve and the induction effect of the coupling must be considered. When, therefore, the circuit is generating oscillations the wave length is a little greater than that obtained from the formula $\lambda = 59{\cdot}6\sqrt{L_2K_2}$. The grid capacity effect in a valve of the French receiver type is about 0·000015 mfd., in a French horned type it is about 0·0000085 mfd., and in a Marconi V.24 valve it is about 0·00001 mfd., all measured when the filament is heated under usual receiver conditions. Modifications of these methods of generating oscillations by a valve will be considered in subsequent chapters, especially in those dealing with C.W. Transmission and Transmitters.

Oscillating Circuit on the Grid.—A valve can be made to generate oscillations, and pass oscillating currents through a condenser, or other capacity effect, connected across the grid coil L_2 instead of the plate coil. The plate and grid circuits can be coupled by mutual induction between the coils, as shown in Fig. 44.

The tuning of the circuit L_2K_2 will now determine the frequency of oscillation and wave length of radiation, provided the plate

circuit is kept well below resonance. As before, any small change of plate current, such as would be caused by completing the plate circuit or coupling the coils, will induce a potential in the grid circuit which modifies the plate current, and with a correct value of coupling oscillations are built up and sustained. The condenser K_2 may be replaced by the capacity of an aerial circuit, which includes L_2, or oscillations may be induced in the capacity of the aerial circuit by inductively coupling the latter to L_2. It is easily recognised that such an arrangement is that employed in receivers with valve detectors, where the valve gives high frequency amplification by a reaction back from the plate circuit.

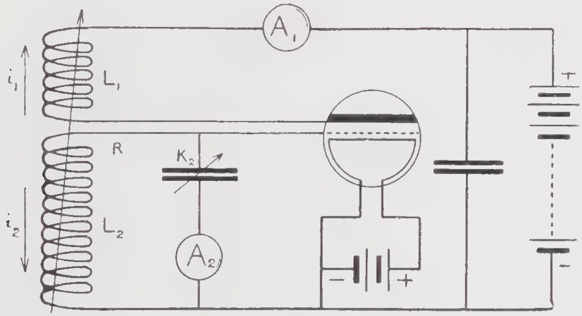


Fig. 44.

Various modifications of these have been fully described in Chap. IV.; it was there pointed out that the receiver was most sensitive when the valve was just at the limit, or threshold, of generating oscillations. If the valve is oscillating spark signals will become hoarse in tone owing to the beats formed; for the reception of undamped oscillations, *i.e.* C.W. signals, it is necessary that the valve should be oscillating in order to form beats, unless a separate heterodyning arrangement is employed externally to the valve receiver.

A simple method of explaining the fact that oscillations can be sustained with such an arrangement has been given by Prof. J. S. Townsend. Suppose R is the resistance of the oscillating circuit L_2K_2, where K_2 may be a variable condenser as shown in Fig. 44, or an aerial-earth circuit connected across L_2, and let i_2 be an oscillating current in L_2. If an E.M.F. equal to $R \times i_2$ can be induced in L_2 in phase with the current i_2 it will wipe out

the ohmic drop and therefore the resistance effect, and if it is greater than Ri_2 it will sustain oscillations of current in the circuit L_2K_2. Now if L_1 is coupled to L_2 with a mutual induction $-M$, and a pulse of the plate circuit current of value i_1 occurs in L_1 it will induce in L_2 a potential equal to $-M\frac{di_1}{dt}$. But $\frac{di_1}{dt}=\frac{F}{r}\times\frac{dV_g}{dt}$, where F is the voltage amplifying factor of the valve and r is the resistance of the plate circuit. Now $\frac{dV_g}{dt}$ may be written $\frac{i_2}{K_2}$, therefore the resistance R of the oscillating circuit on the grid will be wiped out if $Ri_2=\frac{MF}{r}\times\frac{i_2}{K_2}$, or if $M=RK_2\times\frac{r}{F}$. If M is greater than $RK_2\times\frac{r}{F}$ oscillations will be generated, and sustained by the valve at a frequency depending on the period of the circuit L_2K_2, into which the capacity effects of the coil and the valve itself will enter. These have not been considered in the above explanation.

If M is just equal to $RK_2\times\frac{r}{F}$ the resistance of the aerial or other oscillating circuit on the grid is neutralised for the frequency to which it is tuned, and this means that the oscillations induced in it by arriving ether waves at the frequency of the current will have a larger amplitude than otherwise would be the case; this is one reason why such a valve circuit is so sensitive for reception.

If M is just less than $RK_2\times\frac{r}{F}$ the resistance of the oscillating circuit is largely neutralised for oscillations of the given frequency, so that good oscillations can be induced in it by weak external ether pulses, or signals arriving, but oscillations will not be sustained by the valve when the external forces cease.

We thus see why a valve circuit arranged for reception of spark signals is most sensitive when the valve is just on the point of oscillating, and why the note becomes hoarse when the reaction coupling is made too tight. The sensitiveness of a valve receiver will be further discussed in Chap. VII.

The mutual induction between the coils must be of negative sign; by another method of calculation Prof. Gutton finds the conditions of sustaining oscillations to be :—

(1) That the absolute value of M must be smaller than FL_2.

(2) That $M(FL_2 + M)$ is negative, and greater than $\frac{Rr}{\omega^2}$: if we take ω to be approximately $\frac{1}{\sqrt{K_2 L_2}}$ this gives :—

$$M(FL_2+M) > RrK_2L_2.$$

From these it follows that the value of M must lie between two limiting values, and that the oscillations will not be sustained if the coupling is too tight : we already know that they are not sustained if it is too loose.

NOTE.—*A proof for the oscillating condition with inductive coupling.*—The equation of the plate current given previously can be written :—

$$ri_c - Kr\left(-R\frac{di_c}{dt} - L\frac{d^2i_c}{dt^2}\right) = -Ri_c - L\frac{di_c}{dt} - FM\frac{di_c}{dt}$$

$$\therefore\ KrL\frac{d^2i_c}{dt^2} + \frac{di_c}{dt}(KRr + L + FM) + (r + R)i_c = 0$$

or

$$L\frac{d^2i_c}{dt^2} + \frac{di_c}{dt}\left(R + \frac{L + FM}{Kr}\right) + \frac{1}{K}\left(1 + \frac{R}{r}\right)i_c = 0$$

Let $i_c = \epsilon^{mt}$; then $\frac{di_c}{dt} = m\epsilon^{mt} = mi_c$, and $\frac{d^2i_c}{dt^2} = m^2i_c$;

therefore the equation can be written :—

$$Am^2 + Bm + C = 0$$

whence

$$m = \frac{-B}{2A} \pm \sqrt{\frac{B^2 - 4AC}{4A^2}}$$

$$\therefore\ i_c = \epsilon^{-\frac{B}{2A}t} \times \epsilon^{\pm\left(\sqrt{\frac{B^2-4AC}{4A^2}}\right)t} \times \text{constant.}$$

The first term determines whether the first pulse of current will settle down to a steady value or build up into oscillations, according as $-\frac{B}{2A}$ is negative or positive respectively. Since A=L it is necessarily positive, therefore $-\frac{B}{2A}$ is positive only when B is negative. Thus the current will oscillate if B is <0, *i.e.* if $R + \frac{L+FM}{Kr} < 0$. The second term in the expression for i_c determines the time of pulse, therefore also the oscillating frequency when the part under the radical is negative. The pulsation—

$$\omega = 2\pi f = \sqrt{\frac{4AC - B^2}{4A^2}} = \frac{1}{2A}\sqrt{4AC - B^2}$$

$$= \frac{1}{2L}\sqrt{\frac{4L}{K}\left(1 + \frac{R}{r}\right) - \left(R + \frac{L + FM}{Kr}\right)^2}$$

At the limit of oscillations when $R + \frac{L + FM}{Kr} = 0$ this gives the oscillating frequency—

$$f = \frac{1}{2\pi\sqrt{LK}} \times \sqrt{\left(1 + \frac{R}{r}\right)}$$

It is thus seen that the frequency of the oscillations at this limit is very nearly equal to the natural frequency $\frac{1}{2\pi\sqrt{LK}}$ of the circuit; generally, however, the coupling is a little closer than the limiting value and this has the effect of reducing the frequency, or increasing the wave length.

QUESTIONS ON CHAPTER V.

1. Give a simple explanation with diagram of a method by which a suitable valve may be made to generate oscillations.
2. For a given filament temperature and plate potential what determines the amplitude of the oscillations set up in the plate current ?
3. Why does the value of the plate current in a valve generally change when the valve starts oscillating ?
4. The plate current in a generating valve may be only 40 milliamps, when the current delivered to an aerial circuit connected to it is 200 milliamps. How can the aerial current be so much greater than the plate current ?
5. Why is it better in some cases not to include all the aerial inductance in the coupling effect of a valve generator ?
6. Why is it that a valve may sometimes generate oscillations when the mutual coupling between its plate and grid circuits is of wrong sign ?

CHAPTER VI

LOW FREQUENCY AMPLIFIERS

THE simplest employment of a valve is as a relay for electrical pulses of telephonic, or audible, frequency: a preliminary description of this use of a valve has been given in Chapter II. Weak pulses are made to act through a step-up transformer, inducing

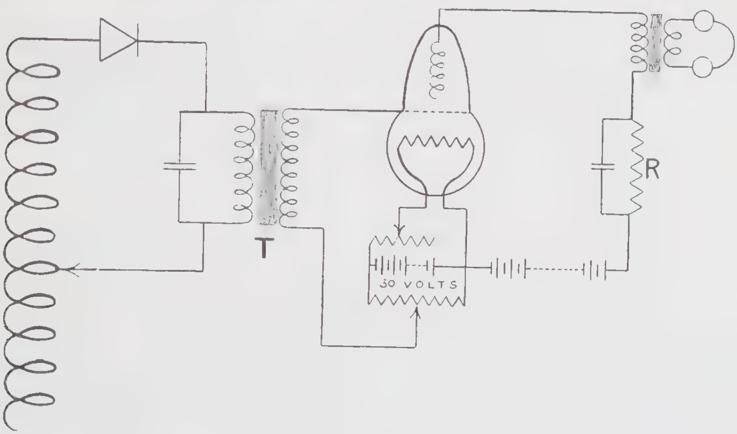


FIG. 45.

corresponding pulses of potential in the secondary: these act on the valve grid and set up pulses of current in the plate circuit.

Before dealing with the design of amplifiers employing more than one valve, which have come lately into general use, it may be interesting to review the earlier attempts at L.F. amplification.

The Lieben-Reisz valve when first brought out was used as a relay for low frequency current pulses, its circuit being as shown in Fig. 45. The weak rectified low frequency pulses from the detector were passed through a step-up iron core transformer. The secondary of the transformer had potentials induced in it

which were applied to the grid-filament circuit of the valve, in series with a steady potential on the grid obtained from the potentiometer. The potentiometer was connected across the battery which lights the filament. The valve was one of the soft vacuum type, hence the necessity of a high resistance R in the plate circuit, to limit the value of the current which flows through the plate circuit and from the high tension battery if the valve gets too soft. A similar high resistance was used in the H.T. battery circuit of the first Round valves.

This relaying effect of a valve for low frequency current pulses must not be confused with valve amplification; no doubt all relaying ensures amplification of effects, but we may have reaction amplification as well as relaying amplification. Thus in Round's connections for double magnification (see Fig. 22) not

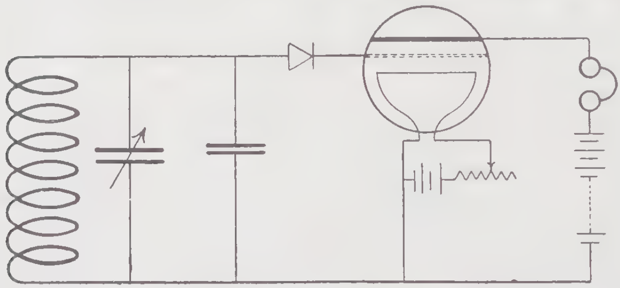


FIG. 46.

only does the valve relay but the resulting current pulses are led back to react on the grid circuit, and thus give rise to further amplification.

Haraden Pratt has described experiments which were made at California University using a crystal detector in series with the grid of an Audion, as shown in Fig. 46, by means of which the audibility was ten times stronger than when the crystal was used alone. It will be found that this method of connection does not give as good results as the other methods herein described.

Armstrong proposed a method of making one valve amplify both the high frequency oscillations and the low frequency pulses; the connections are shown in Fig. 47. The high frequency oscillations which are set up in the plate current induce back into the grid circuit through the coil R, as previously described, while the low frequency pulses in the plate circuit induce back into the grid circuit through the transformer T. The condensers C_1 and C_2

act as paths for, or bye-pass, the high frequency currents, at the same time serving to tune the transformer T approximately to the audio frequency. Coil L helps to tune the plate circuit and thus give a further amplifying effect.

Round's method of double magnification has already been described and shown in Fig. 22. Since the arrival of the Pliotron, French, and other hard vacuum valves it is more customary to detect and amplify the high frequency oscillations with a valve, a crystal and valve, or a set of valves in cascade, and

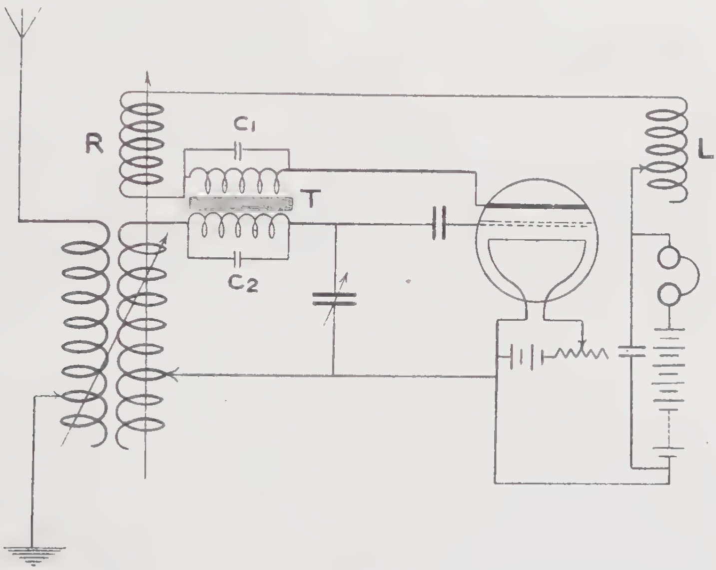


Fig. 47.

to use an entirely separate valve system for low frequency amplification.

In Chapter II. reference was made to the fact that two or more valves could be connected in cascade to relay, or amplify, pulses of telephonic or audio frequency. At present it is not usual to employ more than three valves in cascade for this purpose; when adjusted for most sensitive operation inter-oscillations are likely to be set up between the valve circuits, developing noises which interfere with the reception of signals. It will be readily understood that the more valves there are in cascade the more difficult it is to prevent these inter-oscillations. In practice it is

found that a three-valve amplifier is suitable for all purposes and it can be made to operate quite steadily.

In Chapter II. it was explained that the connections of the two valves in cascade in Fig. 3 could be simplified so that one L.T. and one H.T. battery would serve for the filaments and plate circuits of both valves. The necessary modification of connections is shown in Fig. 48; here the 4-volt battery, B_1, heats both filaments, and the temperature of the filaments can be regulated to some extent by the variable rheostat R. The plates of the two valves are connected to the positive terminal of the battery B_2, that of the first valve through the primary of the telephone transformer T_2, that of the second valve through the telephone

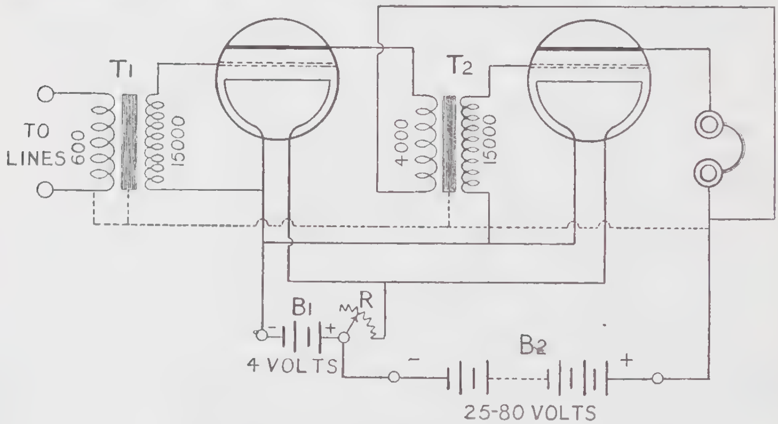


FIG. 48.

receivers; the negative terminal of the battery is connected to the filament circuit as shown.

Weak current pulses which require to be relayed, or amplified are passed through the primary of the first transformer, T_1, at the terminals "To LINES"; they will induce pulses of potential in the secondary winding of T_1 which is connected to the grid and filament of the first valve, and these pulses of potential of the grid with respect to the filament will cause corresponding but larger pulses of current in the plate circuit of the valve. These amplified pulses of current pass through the primary of the intervalve transformer, T_2, and set up pulses of potential in the secondary which is applied to the grid and filament of the second valve; this causes amplified pulses of current in the plate circuit of the

second valve, and therefore in the telephone receivers which are included in this circuit.

The grid potential is pulsed by incoming signals, and a grid current will flow when its potential is made positive, or higher in potential than the lowest potential point on the filament, to which the grid is shown connected in Fig. 48. This grid current will flow through the secondaries of the transformers and cause a slight demagnetising reaction. The grid current is very small, and its action very feeble, but it can be still further reduced if the grid is made lower in potential than the lowest potential point on the filament. One method of doing this would be to adopt the connections shown in Fig. 49. Assuming that 4 volts are applied to the filament through the rheostat R, there will be a

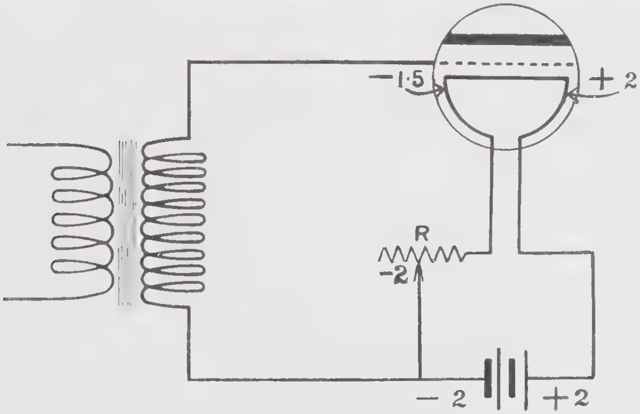


Fig. 49.

drop of, say, 3·5 volts in the filament and 0·5 volt in the rheostat. As shown the lowest potential on the filament is −1·5 volts whilst the grid connected through the secondary of the transformer to the negative pole of the battery is at −2 volts, hence no current will flow in the grid circuit even if its potential is raised 0·5 volt by the pulsations. The example is exaggerated, but it shows the method of avoiding grid current. Another method will be described later. Again, it has been already pointed out that if the plate potential is decreased the resistance between the grid and the filament is lowered; to avoid grid current if the plate potential is decreased the filament temperature should also be decreased, by inserting more of the filament rheostat. This will also have the effect of reducing the grid potential slightly.

As regards the plate circuit battery the positive terminal is always connected to the plate, and it is a question of deciding whether we shall connect the negative terminal to the positive or negative end of the filament. Suppose the plate battery is 50 volts and the filament drop of potential is 4 volts. By connecting the plate battery negative to the positive end of the filament the plate is 50 volts higher than this end and 54 volts higher than the negative end, giving an average of 52 volts between plate and filament. By connecting it to the negative end of the filament the plate is 50 volts higher than the negative end but only 46 volts higher than the positive end, giving an average of 48 volts. Thus it is best to connect the negative of the plate battery to the positive ends of the filaments so that the filament battery may help to raise the average potential of the plates.

In some of the first amplifiers difficulty was experienced owing to the fact that any slight unbalancing of the valve circuits was liable to set up interoscillations between the valves; these oscillations were of low enough frequency to produce whistling noises which greatly interfered with the interception of signals. The windings on the transformers are of high inductance and it requires but a small capacity effect, acting with this inductance, to form a circuit of audible frequency. The capacity effect between the coils on the transformers, and even between the various leads in the apparatus, may be sufficient to produce this; the valves will then generate oscillations as has been described in Chapter V. Valves which do not generate oscillations easily may be designed for use in L.F. amplifiers; some German designs of this type of valve are discussed later in Chapter X.

Capacity effect can be reduced by keeping the wiring leads well apart, and even by leaving a small space between the primary and secondary windings on the transformers; by careful design it is thus possible to reduce the capacity and at least ensure that if oscillations are set up they will be at a frequency high enough to be inaudible. But any unbalancing effect between the valves may cause oscillations of different frequencies to be set up which will produce audible beats. Such unbalancing may be produced by induced differences of potential in the metal parts of the apparatus. To eliminate these as far as possible the French designers, under Col. Ferrié, connected one line terminal, the laminated cores of the transformers, and the metal casing of the telephone receivers to the positive terminal of the high tension battery, so that they should all be at the same potential. In

Fig. 48 this connection is shown by a dotted line. By careful design and assembly of the parts of the transformers, and by connecting the telephone receivers to the plate circuit of the last valve through a telephone transformer, parasitic noises within the amplifier itself can be almost entirely eliminated.

It has been already remarked, in connection with high frequency amplification by reaction on a wireless receiver, that a valve or valve apparatus amplifies oscillations best when it itself is on the point of generating oscillations; this will be explained in a subsequent Chapter. Therefore, to obtain loudest signals, the potentials on the circuits of the valves of a L.F. amplifier should be arranged so that the valves are on the point of generating oscillations, or are actually generating oscillations of feeble intensity. Thus it is not necessary in the design and use of an amplifier to avoid oscillation of the valves but to avoid oscillations at acoustic frequencies, or unbalanced effects which will produce audible beats. Again, it is possible by shunting the transformers with condensers of suitable capacity to give the valve circuits a pre-determined low frequency, say 800 or 1000, and thus make the amplifier selective, so that it responds better to signals carried on a note of this frequency than any other.

In Figs. 2 and 3, Chapter II., and in Fig. 48, the telephone receivers are shown directly connected into the plate circuit of the last valve; for various reasons, which have been already discussed, this is not good practice. For reasons which will be considered later in the Chapter it is advisable to have tappings on the primary of the first transformer, connected to a multiple contact switch, so that its resistance or the ratio of transformation may be varied. Adopting these modifications the connections of a three-valve low frequency amplifier would then be as shown in Fig. 50; here the primary of the first, or line, transformer is shown with five tappings brought to the multiple switch S, and the telephone receivers are connected to the plate circuit of the third valve through the medium of the telephone transformer T_4. It will be seen that, apart from the valves, batteries, and telephone receivers, the L.F. amplifier consists of transformers, and its efficiency will depend on their design which may now be considered. In all electrical circuits where currents are passed into a coil on an instrument or other apparatus for any purpose, such as measurement, best results are obtained when the coil has a resistance of approximately the same value as that of the circuit into which it is connected. For this reason high resistance

telephone receivers are used in series with a high resistance crystal detector, and low resistance telephone receivers in series with a low resistance magnetic detector, or in series with the low resistance winding of a step-down telephone transformer. Therefore when telephone receivers are replaced by a transformer the resistance of the primary coil of the transformer will be governed by the resistance of the circuit into which it is connected.

Applying this argument to the transformers in a L.F. Amplifier we can arrive at a decision as to the resistance of the windings. If the Amplifier is connected to a wireless receiver, to amplify the low frequency or telephonic pulses, the primary of the first transformer will be connected in series with the crystal or valve detector: therefore it should have a fairly high resistance. On the other

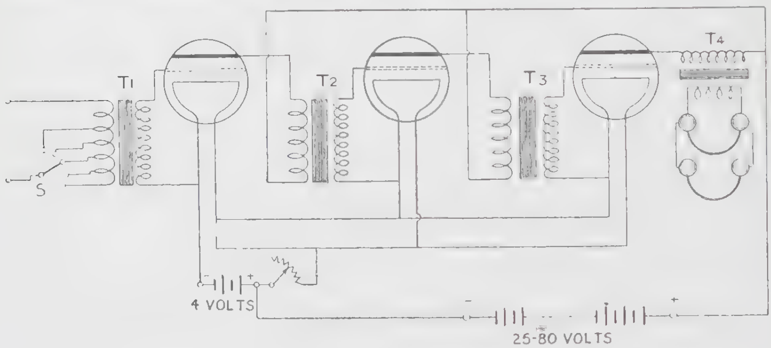


Fig. 50.

hand, if the Amplifier is connected to an earth base, as in the case of Listening Sets, or in reception from power buzzers, the earth base will probably have a resistance of 100-500 ohms, depending on its length and the nature of the soil and substrata; thus the primary of the first transformer should have a resistance of this order. On a loop as sometimes used with Listening Sets the resistance would be still lower.

It is therefore convenient to have the primary of the first transformer wound to a fairly high resistance, but with tappings taken from it to a multiple switch so that the resistance can be chosen to suit the circuit on which the amplifier is employed. There is another advantage in having tappings on the primary of the first transformer—it enables us to vary the ratio of transformation from the primary to the secondary; in practice it is generally found that the position of the selecting switch on the

primary of this transformer which gives the best strength of signals is determined more by best ratio of transformation than by resistance effects. Thus in one Amplifier, whose primary had a total resistance of 1400 ohms with six tappings on it, the best adjustment, when used on a wireless receiver in series with a crystal, was to put the primary switch on the third stud, clearly showing that in this case ratio of transformation from primary to secondary was the deciding factor.

As regards the primary of the transformer in the plate circuit of the first valve, the circuit between the plate and filament in the valve itself has a high resistance and this transformer coil is connected in series with it; therefore this primary should have a fairly high resistance. Here again the issue is complicated with the question of ratio of transformation; shall the primary be full wound to a resistance of 4000 ohms, or shall there be less turns on it, involving less resistance, in order to get a larger step-up effect to the secondary or to reduce the size?

In Amplifiers with which the author has had experience the primary is wound to 2000–3000 ohms. Similar reasoning applies to the primary of the second inter-valve transformer, and to the primary of the telephone transformer in the plate circuit of the last valve.

As regards the secondary of the first transformer the pulses of potential induced in it are applied across the grid-filament of the first valve. The resistance between the filament and the grid is very high; with negative potential on the grid it can be infinity and as the grid potential rises it falls to about 25,000–30,000 ohms so that a grid current flows. The necessary potential effects in the secondary of the transformer are obtained by making it with many turns of fine wire (such as No. 46 S.W.G.), winding it to a resistance of 20,000–30,000 ohms. Apart from questions of ratio of transformation, or number of turns, the high resistance of the secondary, with the high resistance of the grid-filament circuit of the valve, ensures that the current in this circuit will be a minimum; this is an advantage as it means that the secondary coil may be of very fine wire leading to compactness in design; it also means better transformation effects, since a current in the secondary would be opposing the effects of the current in the primary.

Similar considerations apply to the secondaries of the inter-valve transformers which should all be wound to a resistance of 20,000–30,000 ohms. In one Telefunken L.F. Amplifier the secondaries were wound to 36,000 ohms. The secondary of the

last, or telephone, transformer is generally arranged for step-down effects; it therefore has a low resistance in order that low resistance telephone receivers may be connected to it. Thus if two 60-ohm ear-pieces in series are employed the resistance of the secondary should be of the order of 120 ohms.

In L.F. Amplifiers as designed at present it will be found that the resistances of the transformer windings depart very much from the values given above; thus in one 3-valve amplifier the primary of the first transformer has a resistance of 950 ohms with five tappings, the value of the first being only 11 ohms. The resistances of the primaries of the intervalve transformers are 1500 and 2000 ohms respectively, whilst that of the telephone transformer is 1600 ohms. Similarly the secondaries of the first three transformers are only wound to a resistance of 10,000 ohms approximately. These values are probably chosen partly to economise material and keep the transformers small, partly because reliance is placed more on transformer ratio than on resistance values. The first low resistance tapping on the primary of the first transformer is only suitable for use on a low resistance induction loop.

In another Amplifier which gives very good results the resistances of transformer windings are as follows :—

Line Transformer.		First Intervalve.		Second Intervalve.		Telephone Transr.	
Primary.	Secondary.	Primary.	Secondary.	Primary.	Secondary.	Primary.	Secondary.
1400	19,000	3050	14,500	2400	17,200	2760	147

The ratio of transformation cannot be judged by the resistances of the primary and secondary, since they may be wound with wires of different gauge.

The ratio of transformation has varied in different Amplifiers designed up to the present; for the first three transformers it has been approximately 1 : 3·5 in one case, 1 : 4 in another, 1 : 5·5 in a third. These were Amplifiers of British and French manufacture, whilst in the two-valve Telefunken Amplifier employed by the German Army in 1916 the first transformer had a step-up ratio of 1 : 20 and the second one a ratio of 1 : 13. Judging from the results obtained it is probable that a ratio of about 1 : 5 is suitable for use with French valves.

The tappings on the primary of the first or line transformer

enables us to choose a suitable ratio, which will to some extent depend on the strength of the in-coming signals.

Theoretically the square of the ratio of transformation for any of the transformers should be equal to the ratio of the resistances of the circuits to which the windings of the transformer are connected.

Thus for an intervalve transformer the square of the ratio of transformation should be equal to $\frac{r_p}{r_g}$, where r_p is the resistance between the plate and filament in the valve, and r_g is the resistance between grid and filament. The resistance of the plate circuit of a valve on a L.F. Amplifier adjusted for best working is from 25,000 to 40,000 ohms and that of the grid circuit may be 200,000 ohms or much higher, so that a ratio of 1 : 5 is not enough theoretically. However, there are other considerations to be taken into account, such as the avoidance of capacity effect and consequent parasitic noises, and in practice a ratio of 1 : 5 is found to give satisfactory results. As regards the cores of the transformers these should be laminated, and of some good quality of iron or iron alloy (such as stalloy), which has low hysteresis loss. The cores may be of open type, *i.e.* straight cores of iron wires, or of closed type with complete iron paths for the magnetic circuit. The latter type is the more efficient magnetically and can be made very small and light ; an example of this type of transformer is shown in Fig. 51.

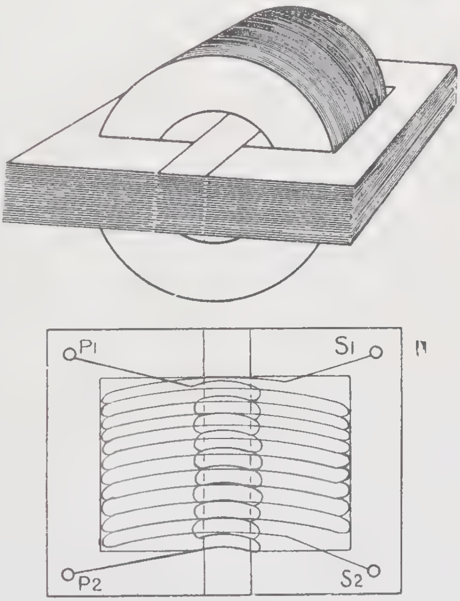


FIG. 51.

As regards the valves it has been explained that the relaying or amplifying action takes place because weak line currents produce potential changes on the grid which cause pulses in the plate circuit current. The pulses in the plate circuit current,

whether of increase or decrease, must be in exact ratio with the weaker pulses of current in the line; if the effects on the plate circuit were greater in one direction than in the other distortion of signals would result. Thus the characteristic curve, showing the plate current plotted against grid potential, should be a uniform sloping line; at least at that part of it on which the valves are functioning in an Amplifier.

In the diagrams of L.F. Amplifiers already given it will be seen that the grids are connected to the filaments through the secondaries of the transformers, therefore normally the grids are functioning at 0 potential with respect to one end of the filaments; referring to the characteristic curves of French valves given in Figs. 7 and 8 it will be seen that the valves in an Amplifier should function at the points marked A on the curves, and that about this point the curves are uniform sloping lines. On the curve in Fig. 7, corresponding to 3 volts applied to the filament, the valves would not function in a L.F. Amplifier at the point A_1 corresponding to 0 grid potential, since pulses of grid potential will not cause uniform pulses of plate current about this point. Again it will be noted that on the curve corresponding to 3·5 volts on the filament and 48 volts on the plate the plate current at point A is 1·6 milliamperes; this is the steady current in the plate circuit when no signals are coming in. Figs. 7 and 8 show that if the voltage on the filament or the voltage on the plate is reduced this value of plate current will be reduced, and therefore the plate circuit battery will last much longer.

Thus it is an advantage to work on as low a curve as possible so that the lives of the batteries may be prolonged, provided that the curve on which the valves are functioning is uniform about zero grid potential. It will be noted that by reducing either the filament or plate voltage the steepness of the curve falls off to some extent; this means that there is less change of plate current with change of grid potential, and consequently reduction of amplifying effect. Thus a reduced voltage leads to battery economy, and as long as good readable signals are obtained battery economy is of as much importance as amplification factor.

The steeper the plate current curve on any plate voltage or filament voltage the greater will be the amplitude of the pulses obtained with pulsing grid potential, *i.e.* the greater the amplification; this steepness of curve depends on the design of the valve. In 1916 the author tested various designs of valves; some were not at all efficient in L.F. Amplifiers because their characteristic

curves were very irregular, or had a poor angle of slope; for example the curves of some of the earlier valves employed by the Germans in the campaign, which are illustrated in Chapter X., are very poor compared to that of the French valve.

Referring to the curve corresponding to 3·5 volts on the filament in Fig. 7, suppose that normally the grid is not at zero potential compared to the filament, or rather that end of the filament to which it is connected, but that it is at −2 volts with respect to the filament. The plate current when no signals are coming in is now only 0·95 milliampere instead of 1·6 milliamperes at the point A, and the curve is still of uniform slope in both directions about this point.

Thus if a small negative potential is put on the grid a valve will take less plate current and still operate efficiently as an amplifier, provided it is not made to function too near the bend of the curve where signals would be distorted. This reduction of plate current economises the plate circuit battery and makes the whole system more efficient. Another advantage of the use of a small negative potential on the grid is that it reduces to a very small value the current in the grid circuit, and brings it to a value which is nearly constant for slight changes of grid potential. Thus the secondary of the transformer which carries it can be wound of thin wire without any undue potential drop; also the potential drop is constant so that variations of grid potential will depend more definitely on variations of current in the primary. The demagnetising effect of the secondary current and its consequent distortion effect are reduced to a minimum.

The necessary negative potential on the grids can be easily arranged; instead of connecting the grids through the secondaries of the transformers directly to the filaments they are connected through a cell, the positive terminal of which is connected to the filaments; if a Dry Cell is used this will make the grids about 1·4 volts negative with respect to the filaments.

A diagram of a 3-valve amplifier arranged in this way is given in Fig. 52, where the grid connections are shown dotted for clearness. Since the grid circuit currents are now very small the dry cell, shown at A in Fig. 52, will last a long time before it requires replacement. One line terminal of the primary of the first transformer is connected to the negative leg of the filament circuit. It is sometimes a great advantage to have a L.F. amplifier so arranged that the first valve can be made to function as a detector, or rectifying valve, if so required. A good example of

this is the amplifier known as Modele 3ter designed at the French Military Establishment in Paris; a diagram of this amplifier is given in Fig. 53.

It is fitted with three line terminals, L_1, L_2, and L_3; L_1 and L_2 are for connection to a wireless receiver circuit, but when the

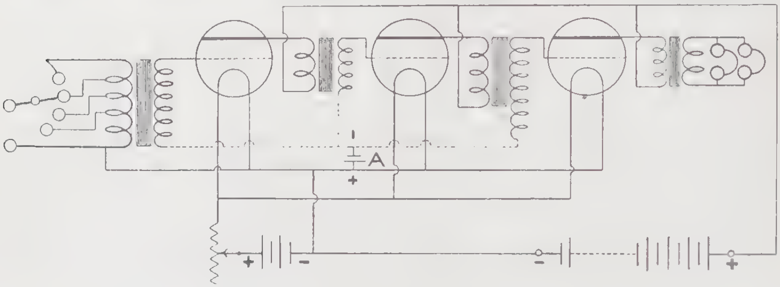


Fig. 52.

amplifier is employed on an earth base to receive signals through the earth (Telegraphie par Sol), and on telephone lines, the base is connected to the terminals L_1 and L_3. Therefore the instrument can be used efficiently in the following three ways:—

(1) As an amplifier for weak earth or telephonic currents: turn switch to B.F. (Basse frèquence) and connect the lines to L_1—L_3. Switch 1 connects the lines through a portion of the

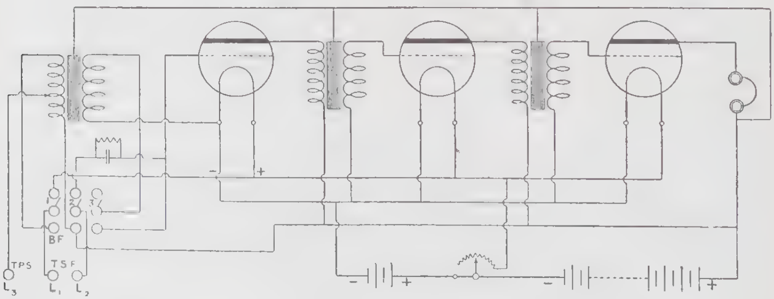


Fig. 53.

primary of the transformer, which portion has a suitable low resistance. Switch 3 connects one end of the secondary to the grid of the first valve, the other end being connected to the filament.

(2) As an amplifier of telephonic pulses in a wireless receiver

which have been already rectified by a crystal or other detector; turn switch to B.F. and connect telephone terminals on the receiver to $L_1 - L_2$ (T.S.F.); then the whole of the transformer primary is in circuit and it has a resistance suitable for this connection, the grid still being connected direct through the secondary to the filament. T.S.F. represents Telegraphie sans Fils, and T.P.S. is Telegraphie par sol.

(3) As a detector and L.F. amplifier on a wireless receiver circuit; turn switch upwards and connect $L_1 - L_2$ (T.S.F.) across the wireless receiver circuit. The first transformer is now cut out altogether. L_1 is connected to the positive end of the filament, and L_2 to the first grid in series with a small leaky condenser; this makes the first valve act as a detector, the other two still amplifying the low frequency pulses.

The Telefunken Company produced a 2-valve amplifier (Type E.V. 89d), for connection to a wireless receiver which was employed by the Germans in the campaign; a diagram of its connections is given in Fig. 54.

A point of interest in this amplifier is the use of iron wire baretters in series with the filament resistances, R_1 and R_2. These baretters consist of little coils of iron wire enclosed in hydrogen in a glass tube; they are similar to those formerly employed in series with the filaments of Nernst lamps to keep the filament current steady even if the applied voltage fluctuates. The resistance of iron wire increases with its temperature, so that if the battery voltage rises, and the current in the filament circuit tends to increase, the resistance of the iron wire (raised in temperature by the current) increases, and so increases the drop of potential in the wire. The reverse action takes place if the battery voltage falls. Thus the use of these iron wire baretters in series with the filaments tends to keep the filament current and temperature constant; it ensures the possibility of having steady working of the valves on batteries whose voltage may vary, such as Edison accumulators which were largely used by the Germans.

When the filament current is flowing the resistance of the baretter is about 1·75 ohms and of the series resistance about 3·5 ohms. Thus with 5 volts applied the current will be about 0·53 ampere and the voltage on the valve filament about 2·6 volts. These are the proper values for the A.E.G. type valves which were used in this amplifier and which are described in a subsequent Chapter.

The transformers had open cores of iron wire, and were shielded

from all external magnetic and electric inductive effects by totally enclosing them in concentric cases of iron and brass.

It will be seen that there are no adjustments to make once the proper values of plate and filament voltages have been chosen.

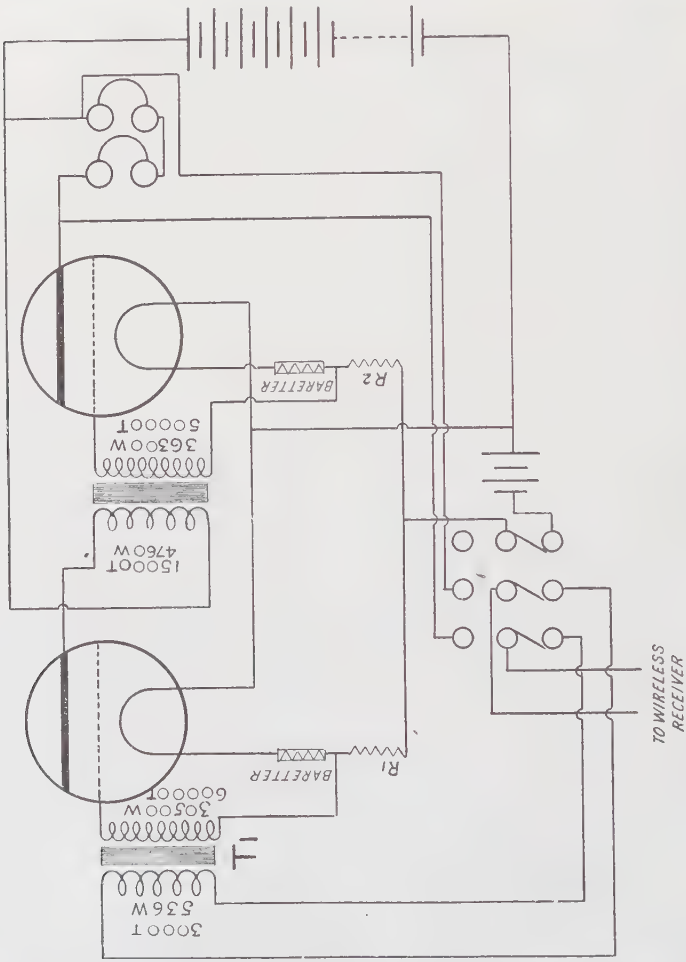


FIG. 54.

When the change-over switch is closed upwards the telephones are connected directly to the wireless receiver circuit and the lighting battery of the valve filaments is switched off; when the switch is closed downwards the battery circuit is completed and

the receiver circuit connected through the transformers and valves to the telephone receivers. The receivers were single ear-pieces of 2000 ohms resistance.

Owing to the design of the valves used in this amplifier its action was very steady with an absence of microphonic noise effects; also, since the valves took a very small plate current, the H.T. battery was a light and compact one of 90 volts without tappings. However this instrument did not give as good signal amplification as those used by the French and British military services, even when French valves were used in it on their proper voltage.

Low Frequency Amplifiers have the disadvantage that they amplify all effects due to parasitic currents or discharges, and the noises thus set up in the telephone receivers considerably interfere with the reception of signals. When an amplifier is employed on an earth base, to pick up signals from power buzzers by earth conduction currents, much trouble is often caused by stray earth currents or atmospheric discharges.

During the campaign in France static discharges were very prevalent in the hot summer months, at times making it quite impossible to read signals in an amplifier on an earth base. The effects of ordinary stray earth current, due to unequal earth potentials, can to some extent be eliminated by introducing an opposing E.M.F. in the earth base, for which a potentiometer is convenient, but this is of no service when discharges are taking place from the earth's surface into the atmosphere. Methods of eliminating noises due to stray currents or discharges will be described in Chap. XV.

When an Amplifier is connected to a wireless receiver parasitic noises will be set up by atmospheric discharges, battery leakage currents, local action in the H.T. battery, imperfect connections, and stray capacity or induction effects. Much of the trouble caused by irritating noises in the amplifier receivers can be traced to faults in the apparatus or carelessness in connecting up; by taking proper precautions it is generally possible to greatly minimise the effects.

Atmospheric discharges are always recognised by crashing noises in the telephones; if a continuous boiling noise is heard it is probably due to leakage, local action, or other fault in the H.T. battery, which should be examined and if necessary replaced. Frying or whistling noises may arise from unequal potentials in the metal parts of the instrument such as transformer cores and

the metal cases of telephone receivers; to obviate this trouble all the cores and metal work are connected together and connected to the positive terminal of the H.T. battery in some French designs of amplifiers. Where this is not done a high-pitched whistling noise is often heard if the metal cases or head bands of the telephones are touched; this is because the capacity of the body is setting up unbalancing effects which are causing inter-oscillations in the valve circuits. Again, whistling noises will generally result if one or both of the lines of the amplifier are broken or disconnected, whether it is used on an earth base or on a wireless receiver, and if persistent whistling is heard one of the first things to look for is a broken connection. When the amplifier and the valve potentials are adjusted for most sensitive working, with some valve designs, the circuits are just on the point of interoscillating, so that if the damping effect of the line or wireless receiver circuit is disconnected they interoscillate freely with consequent whistling.

Whistling or other noises may be caused by the fact that the connections to the telephones, lighting battery, or H.T. plate circuit battery are touching each other; care should therefore be taken to have all connecting wires as short as possible, and symmetrically laid out so that they are not lying across each other. All connections should be firmly made and precautions taken that no masses of metal are near the amplifier. In damp places the amplifier and the battery should be supported on insulating material such as dry wood, glass, or porcelain; also the operator should avoid standing on damp soil, damp wood, or metal.

With some valve designs there is a microphonic effect in L.F. amplifiers so that the slightest jar given to the apparatus, such as tapping it with the finger or even walking near it, is strongly magnified in the telephone receivers. This is very apparent where French valves are used; it is mainly due to the non-rigidity of the grid which causes it to vibrate with the slightest movement; this sets up pulsing effects in the plate current which therefore reproduces in the telephones the cause of the vibration. This microphonic effect may be used as a test for the proper adjustment of the apparatus since it is only strongly apparent when the valve circuits are adjusted for most sensitive working.

It will often be found that changing the order of the valves in the amplifier improves the signals, either because they fit better in the new sockets, or because of some slight difference

in their characteristic curves which makes one more suitable to employ as No. 1 valve than another. Again, with those amplifiers in which one line terminal is connected to the filament circuit as in Fig. 52, it will often improve signals to reverse the line connections.

Attention may again be drawn to the proper adjustment of filament and plate voltages; the best values to employ will always depend on the design of the valves used, but generally the lower the filament voltage the less the H.T. volts required for maximum sensitivity. Excessive voltage in either circuit only gives harsh and broken signals, and means a wasteful use of excessive battery current. Parasitic noises can be decreased by reducing the L.T. or H.T. battery volts, or by reducing the number of valves in cascade.

The most intelligent and economical adjustment of an amplifier and its batteries is that which will give signals which can be comfortably read rather than loudest possible signals; this applies more particularly to the amplification of speech.

The current taken from the H.T. battery at 50 volts is approximately three times that taken at 25 volts, in an amplifier of the type shown in Fig. 50, and it may well be that 25 volts on the plate gives as satisfactory results as 50 volts.

Before leaving the question of the amplification of signals in a wireless receiver it may be useful to consider the suitable employment of High Frequency and Low Frequency Amplifiers. Amplification is required for either of two reasons:—

(1) To make weak effects strong enough to give reasonable signals.

(2) To strengthen signals so that they can be read through the interference of external noises or of other jamming signals.

Generally one may say that for long distance work, when the oscillations set up in the receiver circuits by the ether waves are very weak, it is best to amplify them first by means of an H.F. Amplifier before rectifying them through a crystal or other detector; if necessary a L.F. Amplifier can then be used behind the detector. Where a valve is used as the detector it can be arranged to give H.F. amplification through the medium of a reaction coupling in its plate circuit, as has already been explained, and if the plate circuit is tuned a good selectivity with absence of jamming is obtained. If two valves are coupled in cascade by tuned circuits to give H.F. amplification the tuning is very sharp.

On the other hand, if the object is to obtain signals loud enough

to be read through interfering noises low frequency amplification will be sufficient, but care should be taken that the wireless receiver circuits are suitably designed for use with the amplifier. Capacity effects should be reduced to a minimum; where there is a coupled closed circuit it should be tuned mainly by tappings on the inductance coil, with a variable shunt condenser whose maximum capacity is very small, such as the Billi Condenser employed by the Marconi Company.

The simplest amplifying arrangement, and one that will serve most purposes except very long range reception, is to employ three valves; the first arranged to act as a detector and give H.F. amplification through the medium of a reaction coupling of its plate circuit, the second and third valves arranged to give L.F. amplification, with transformer coupling from the first to the second and from the second to the third.

It is no recommendation of an amplifying arrangement to say that it gives signals which can be read in the next room; such a result only means deterioration of telephone receivers and waste of battery power. An amplifier is an arrangement which will strengthen up weak or inaudible signals so that they can be comfortably read, even through some jamming.

QUESTIONS ON CHAPTER VI.

1. Draw a diagram of the circuits of a 3-valve L.F. amplifier.
2. In a L.F. amplifier which is the best point on the filament circuit for connection to the grid circuit?
3. What difference does it make if the plate circuits of a L.F. amplifier are completed to the positive end or the negative end of the filament battery?
4. On what part of the plate current curve should the valves in a L.F. amplifier function? Give reasons for your answer.
5. What will be the effect in a Low Frequency Amplifier if?—
   (*a*) The plate circuit battery is in bad condition.
   (*b*) The valve grids are not of rigid design.
   (*c*) One line connection is broken.
   (*d*) Connecting wires are long and lying close together.
6. Write a short account of the considerations which govern the design of the transformers used in a L.F. amplifier Why has it been suggested that the primaries and secondaries of these transformers should not be wound closely over each other on the cores?
7. A fresh adjustment of the plate potential in a L.F. amplifier should generally be accompanied by a fresh adjustment of the filament rheostat. Why is this?
8. Compare the advantages and disadvantages of closed and open transformer cores in L.F. amplifiers.

CHAPTER VII

HIGH FREQUENCY AMPLIFIERS

A High Frequency Amplifier is generally taken to denote an apparatus by which oscillation amplitude is built up, before rectification and subsequent "Note" or "Pulse" amplification. They have been called Ultra-Magnifiers, probably derived from the word Ultra-Audion used by De Forest in connection with an Audion valve circuit used by him.

High Frequency Amplifiers are only required for very weak signals; fairly strong ones can be amplified sufficiently after rectification, whereas very weak oscillations may be damped out altogether in an attempt to rectify them. Thus the most successful design will be one which has a greater amplifying effect on weak signals than on strong ones; this will have the advantage that the weak signals can be strengthened up without accentuating the jamming effect of stronger signals on the same wave length.

It has been described in Chap. VI. how weak current pulses of acoustic or telephonic frequencies may be amplified by valves in cascade, coupling the plate circuit of one valve to the grid of the succeeding one by means of an iron core transformer. It is possible to use a similar method for the amplification of high frequency oscillations; the cores of the transformers would have to be built up of very thin laminations, and the windings would each consist of single layers of few turns. Unfortunately with such a method trouble is experienced on short wave, or high frequency, work, owing to the accentuated effects of parasite capacities; for this reason iron core transformers have not been successfully employed in High Frequency Amplifiers.

The French Wireless Military Staff at Paris, under General Ferrié, has devoted much attention to the design of H.F. Amplifiers using French valves in cascade; one of the methods adopted will be explained with the aid of Fig. 55. Weak oscillations set

up in a receiver circuit are applied across the grid filament of the first valve at the terminals T_1, T_2, the plate circuit including a high resistance *ab*, of about 50,000 to 80,000 ohms. The weak oscillations of grid potential will cause oscillations in the plate current C_p, therefore in the potential drop (C_pR) across *ab*. Thus oscillations of the potential at the point (*a*) will occur, therefore of the plate of the small condenser K connected to it; oscillations of the potential of the other plate of the condenser and the grid of the second valve will therefore be induced, so that the oscillatory effect is stepped up from the first valve to the second.

If a leaky condenser is included, as shown, in the grid circuit

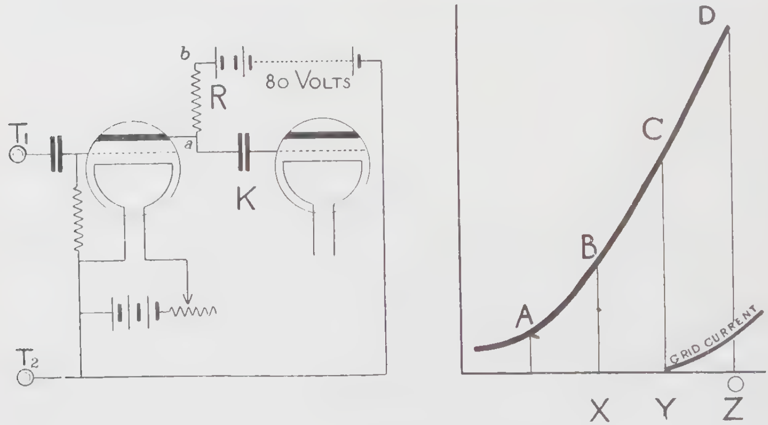


FIG. 55.

of the first valve it may act as a detector, giving a slow variation of potential in *ab*, at telephonic frequency, proportional to the square of the amplitude of the oscillations applied to the grid. In fact, such a leak will be necessary to keep the grid at a mean potential, the leak being connected from the grid to one leg of the filament. The resistances marked 5Ω in Fig 56 are leaks across the grid circuits of the valves.

The amplifying effect on the oscillations will preponderate for weak signals, the low frequency effect with rectification will be greatest for strong signals.

Referring to the valve curve shown on the right of the Fig. 55, it will be fairly steep if about 80 volts are applied to the plate. If the valve is made to function at point A on the curve it will

rectify, but better results are obtained if the valve is worked at point C. If the valve is worked at points B or D weak oscillations of grid potential will cause oscillations of plate current, and rectification is negligible, unless the oscillations of grid potential bring it, at each half cycle, past the point where grid current starts. This will only occur with strong signals. Point D corresponds to zero potential of the grid with respect to the filament, *i.e.* the first grid would not have a leaky condenser in series with it, and at this point the steepness of the curve ensures good amplifying effect on the oscillations set up in the plate circuit.

We must here consider the factors which govern the values of the resistance R, connected in series in the plate circuit, and the condenser K, in series with the succeeding grid. If R is the resistance of ab in Fig. 55, and r the resistance between the plate and filament in the valve, the total resistance of the plate circuit is approximately $(R+r)$; thus if i_p is the change of plate current caused by a change of grid potential V_g the change of potential in the plate circuit is $i_p(R+r)$. This change of potential is equal to FV_g, where F is the voltage amplifying factor of the valve. Since the change of potential, $i_p(R+r)$, in the plate circuit should be localised as much as possible in the portion of the circuit ab, its resistance R should be very large compared to r. Under reception conditions, with about 4 volts on the filament and 80 volts on the plate, r is of the order of 20,000 ohms, therefore R should be of the order of 80,000–100,000 ohms. The resistance R must not be made too large otherwise the plate current will be unnecessarily reduced.

As regards the condenser K, it has to transmit the oscillations of potential from the plate of the first valve to the grid of the succeeding one, by experiencing oscillating charge and discharge effects; therefore its reactance $\frac{1}{2\pi fK}$ should be small compared with that of the leakage path r_1 which shunts it. The shorter the wave length the higher the frequency, and the greater will be $\frac{1}{2\pi fK}$ unless K is reduced; thus the shorter the wave length the smaller should be the capacity of K, its value at any time being proportioned to the resistance r_1 of the shunt across it. If this resistance is 4 megohms K can be about 0·00005 mfd. for a frequency of 100,000, or wave length of 3000 metres; for a lower shunt resistance or a shorter wave length K should have a smaller value.

It is seen that this arrangement of a valve, with a grid condenser

shunted by a leak, will be able to produce rectification when the oscillations are strong enough to bring the point of functioning, as regards grid potential, to a suitable part of the characteristic curve.

Therefore such a cascade arrangement of valves will have rectifying properties as well as giving amplification of the oscillations. It has the advantage of avoiding parasitic effects and noises; it also amplifies weak oscillations better than strong ones such as might be caused by atmospherics. For these reasons it is possible to employ more valves in cascade than are practicable in Low Frequency Amplifiers.

A simple 3-Valve Amplifier, designed on these principles by the French Military Service, is shown in Fig. 56, and requires no further explanation. Attempts have been made to design such an amplifier with choke coils instead of non-inductive resistances in the plate

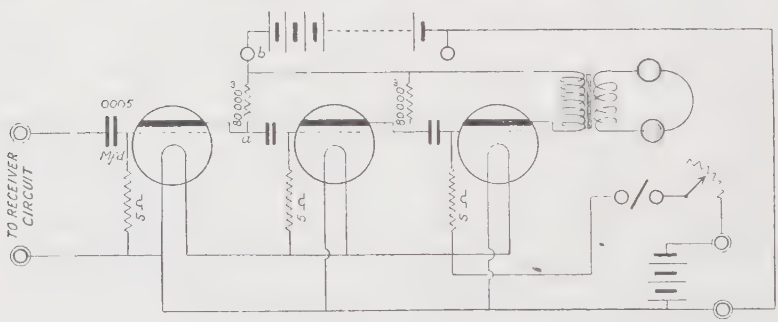


FIG. 56.

circuits. The coils were wound to a resistance of about 1200 ohms, with fine wire on an open laminated iron core and therefore had a high inductance (L). The impedance of a choke coil to alternating current is $\sqrt{(2\pi f L)^2 + R^2}$ ohms.

One disadvantage of their use is that the impedance varies with the frequency (f) and therefore with the wave length; another is the difficulty of making coils of equal impedance, and any inequality will lead to unbalanced effects in the plate circuits.

It is, of course, possible to use a Low Frequency Amplifier after the High Frequency Amplifier, and the French Military Authorities have designed a combined amplifier as shown in Fig. 57. In this arrangement the first five valves act as a high frequency amplifier, the sixth as a detector, and the last two as a low frequency amplifier.

By means of switch S_2 the telephone transformer can be connected into the plate circuit of the 6th, 7th, or 8th valve, so that the 7th or 8th valve, or both, need not be employed unless desired. K is a very small condenser effect consisting of a movable vane, connected to the grid of the 1st valve, and two fixed vanes, one of which is connected to the plate of the 3rd valve while the other can be connected through switch S_1 to the plate of the 2nd, 4th, or 5th valve, or to the filament terminal of the 1st valve. This provides a capacity reaction which, when suitably adjusted, can be made to greatly increase the strength of signals; it can also be used to set up oscillations in the valves so that C.W. reception becomes possible. The best reaction connection will generally depend on the wave length of the received signals.

The action of this condenser reaction is very simple; consider

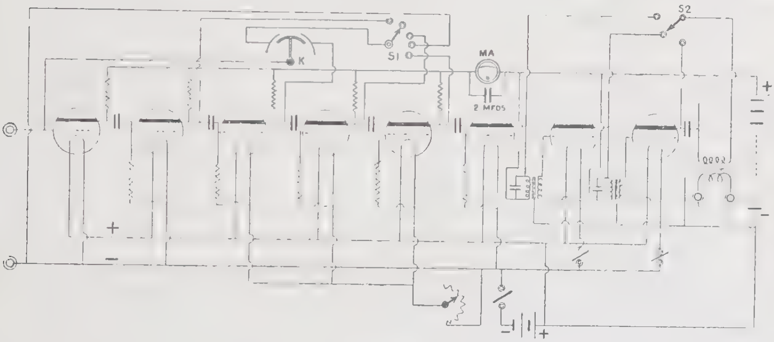


FIG. 57.

the instant when the incoming oscillations cause a rise of grid potential of the first valve; this will increase its plate current, therefore will increase the ohmic drop of volts $C_p(R+r)$ in the plate circuit, and the plate potential falls. This fall of plate potential induces a fall of grid potential in the second valve through the coupling condenser K. The plate current in this valve will therefore fall and the plate potential will rise; a similar action being repeated from valve to valve.

We might tabulate the results for four valves as follows:—

	1st Valve.	2nd Valve.	3rd Valve.	4th Valve.
Grid Potential.	Increase.	Decrease.	Increase.	Decrease.
Plate Current.	Increase.	Decrease.	Increase.	Decrease.
Plate Potential.	Decrease.	Increase.	Decrease.	Increase.

The increase of energy in the last plate circuit will mainly be employed, through the telephone receivers or transformer included in its circuit, to vibrate the telephone diaphragms. If, however, a small portion of it is transferred to the grid of the first valve, by means of a condenser reaction, this will give increased grid potential effects, to be again amplified through the successive valves. Thus the amplification effect is much increased by the use of this capacity reaction. A little consideration of the phase relationships will show that if the first grid is coupled by means of a small condenser to its own plate, or the plate of the third valve, the potential effect on the grid will be decreased and the amplification lowered, for the potential effects on these plates is a decreasing one when that of the incoming oscillations increases the potential of the grid. In practice the phase relationships are not exact owing to parasitic capacity effects, so that it is often possible to increase amplification by reaction from the third plate to the first grid.

On any wave length or frequency, and for any strength of signal, the amplifying effect of the reaction will greatly depend on the value of capacity employed; this implies that the reaction condenser should be a variable one with a maximum value of about 0·00005 mfd. When experimenting with a 3-valve Amplifier Capt. K. Tremellan noted the increased strength of signals obtained when he simultaneously touched terminals connected to the first grid and the last plate. He replaced the capacity effect of his body across the grid and plate by that of a yard of 35/40 twisted flexible cable, and found that the small capacity of the flexible cable was sufficient to greatly increase the amplifying effect of the instrument. About the same time the author noted the same effect, obtained by connecting the first grid and last plate through the body, and found that the body could be effectively replaced by the reaction of a 1-megohm resistance.

It is possible by means of the capacity reaction to make the valve amplifier generate oscillations. We have seen in Chap. V. that a valve will generate oscillations if its grid and plate are suitably coupled by means of a condenser; in the preceding paragraphs it has been explained that if the 2nd, 4th, etc., plates are coupled through a small condenser to the first grid a portion of the oscillating energy in the plate circuit is transferred back to the grid. It passes through the instrument, is amplified, and passed back again to the first grid; oscillations are therefore built up. If the capacity of the condenser is of suitable value oscillations of E.M.F.

will be induced in the coil of the receiver circuit to which the grid is connected ; these will be sufficient to sustain the oscillations and so cause continuous generation. Theoretically, to sustain these oscillations, it is the plate of the 2nd, 4th or other even number of valve which should react back on the first grid through the condenser coupling, but owing to parasitic effects it will be found that oscillations may be sustained by a reaction from any valve except the first : indeed, under certain conditions of applied potentials with some valve designs they may be sustained without any specially added reaction effect.

As the value of the reaction condenser is increased from zero the strength of spark signals will increase, and at a certain critical value they will be found to become hoarse, showing that the valves are generating into the receiver circuit. The frequency of the generated oscillations will be that of the receiver circuit as modified by the added capacity effects of the amplifier. With such an amplifier it is therefore possible to heterodyne and receive C.W. signals on any receiver circuit.

As regards spark signals it was pointed out in Chap. IV. that if a receiver circuit is fitted with a valve detector, whose plate circuit reacted back to give H.F. amplification, the arrangement was most sensitive when the valve was on the point of generating oscillations. With a H.F. Amplifier of the design under discussion the reaction condenser can be adjusted for reception of spark signals so that the system is on the point of generating oscillations ; it will then be in the most sensitive condition. For reception of C.W. signals the reaction capacity is increased in value until the system is actually generating oscillations, and adjustment of the tuning of the receiver will then form beats with the incoming signals, the oscillations in which will be rectified by the Amplifier.

Remarkable results have been obtained with such an Amplifier even without an aerial or earth connection. For long wave stations, such as Coltano, Leipsic, Lyons, etc., it is only necessary to connect the amplifier across a coil of suitable inductance, shunted by a tuning condenser, and the signals can be increased or decreased by orienting the coil with respect to the distant station. For use with these amplifiers General Ferrié employs a "cadre," that is to say a star framework of wooden arms to which several turns of insulated wire are attached by means of small porcelain insulators. The number of turns and mean diameter of the coil depends on the wave length ; the turns are spaced about

an inch apart, and the whole is mounted on a pivoted support, so that the plane of the coil can be oriented in the direction of the station it is desired to pick up.

It was early found with High Frequency Amplifiers, such as those shown in Figs. 56 and 57, that the results were only good on long wave lengths. The poor results on short wave lengths are due to the capacity effects in the valve itself. Referring to Fig. 56 a step-up of oscillating voltage on the grid of the second valve is due to the oscillating potentials across the 80,000 ohms resistance in the plate circuit of the first valve. This oscillating potential depends directly on R, the resistance introduced into the plate circuit, and inversely on the capacity of the plate and its connections; anything which reduces R or increases the plate capacity reduces the oscillating potential.

Now the capacity between the grid and filament of the second valve is in parallel with R, and in an ordinary French valve, where the grid and filament lead-in wires run parallel to each other, down the stem, this capacity is probably of the order of 0·000015 mfd. when the valve is lighted. The reactance of capacity is $\frac{1}{2\pi f K}$ ohms and it is seen that the shorter the wave length or the higher the frequency, the smaller will be this resistance. It is in parallel with the 80,000 ohms, hence, if small, it will seriously lower the impedance of this portion of the circuit, and thus lower the oscillation of potential across it. In fact for short waves there may be no advantage, and at higher frequencies there may be a step-down effect, bringing about a reduction of signals. This is one reason why parasites of high frequency, or local signals of comparatively short wave length are not much amplified by this kind of apparatus.

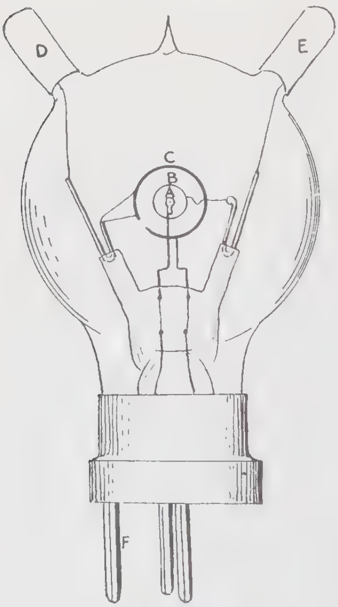


Fig. 58.

The French Wireless Service tried to get over the difficulty by bringing out a special design of their valve which is shown in Fig. 58. Here the capacity effects have been reduced by keeping

the lead-in wires to the plate, grid, and filament well apart. These valves were employed in a 4-valve High Frequency Amplifier, designed for use on waves as short as 200 metres.

A diagram of the amplifier connections is shown in Fig. 59,

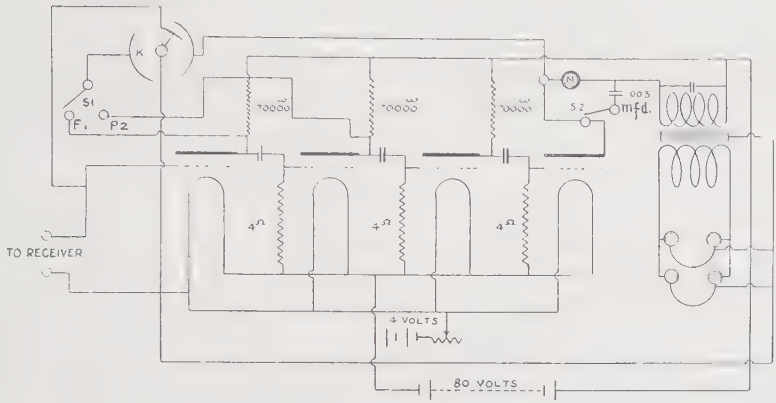


FIG. 59.

and it is seen to be similar to that shown in Fig. 57, which, using ordinary French valves, was found to be suitable for use on long wave lengths. The design of the condenser K is interesting, and is illustrated in Fig. 60; at each side there are three fixed plates

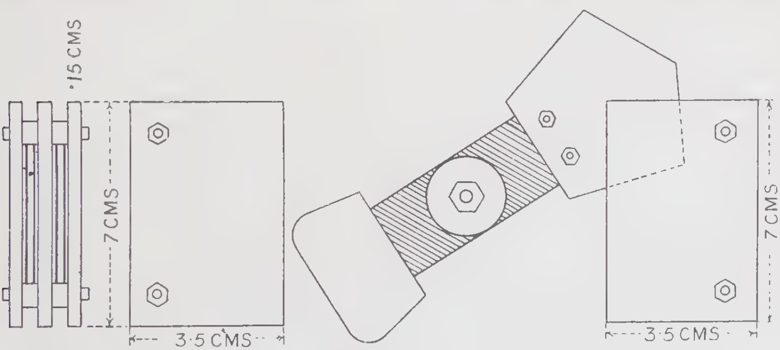


FIG. 60.

of brass $3\frac{1}{2} \times 7$ cms., and 1·5 mms. thick. Two similar movable brass plates are mounted on an ebonite arm, at the other end of which is fixed a mass of lead connected to the negative terminal of the valve filaments. The air-gap between the plates

is approximately 1 mm., so that the capacity effects in this condenser are extremely small.

The use of the milliammeter M in the plate circuit of the last valve is interesting; for a certain setting of the variable reaction condenser, K, the amplifier generates oscillations, and thus can be used to receive C.W. signals by the beat method. Normally the plate current taken by the fourth valve, as read on the ammeter, is 1·8 milliamperes, but when the amplifier generates oscillations this current is reduced, owing to the reduction of grid potential when grid current flows. Signals are best when the valves are just oscillating so that, as the condenser is varied, an inspection of the milliammeter will show the point where the plate current falls and thus indicate the reaction adjustment which sets up oscillations.

Spark signals are received with their natural tone if the apparatus is not oscillating, and will be heterodyned with increase of strength if the reaction is adjusted to promote oscillations. For wave lengths above 500 metres it is best to leave S_1 open and close S_2, oscillations can then be started by varying condenser K. If it is desired to receive spark signals without heterodyning any oscillations in the amplifier can be stopped by closing switch S_1 on the contact P_1, thus reacting between the plate and grid of the first valve.

For waves shorter than 500 metres it is best to leave switch S_2 open; generally also with S_1 open the system will oscillate and heterodyne by adjustment of condenser K. It may, however, be necessary to close switch S_1 to the second plate, in which case the system will oscillate when the moving vane of the condenser is to the left or the right, and will cease to oscillate when this vane is in a midway position. As a matter of fact the results with this amplifier on short wave lengths were not much better than when ordinary valves were employed, and up to the present it has been found difficult to design a H.F. Amplifier which is efficient on short wave, high frequency, oscillations.

The Amplifier is very silent, partly on account of the new design of valve; if necessary a Low Frequency Amplifier may be used behind it in the usual manner. It is very good for C.W. work, especially if the receiver circuits are well designed with high inductance and low capacity effects.

An interesting 4-valve Amplifier, designed for the French Military Service, is shown in Fig. 61. It will be seen that it is an elaboration of double magnification; that is to say both the high

frequency oscillations and the telephonic pulses undergo amplification in the valves.

In this Amplifier the oscillations set up in the plate circuit current of the first valve act on the grid of the second valve through transformer A, and amplification of these oscillations takes place successively in the second and third valves through the medium of the transformers B and C. In the fourth valve, which is arranged for rectification, low frequency pulses are set up, and these are led back to be amplified in the second and third valves through the medium of the transformers D and E. These transformers

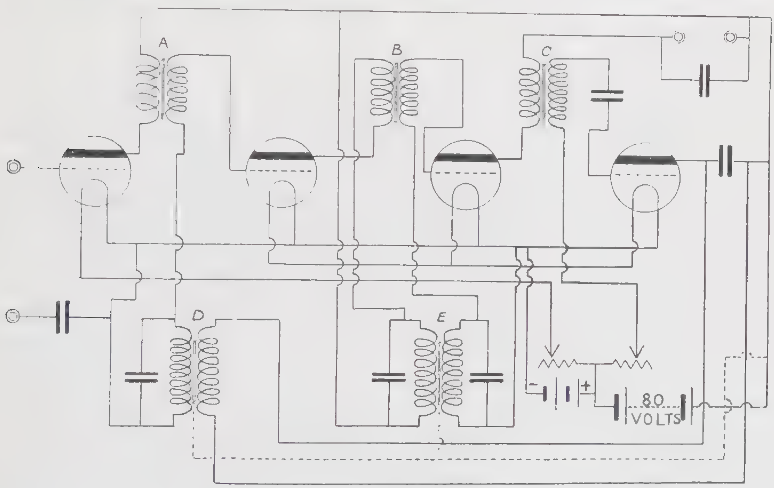


FIG. 61.

(D and E) are shunted by small condensers which provide a path for the high frequency oscillations in the same circuits; it is seen that a crystal or valve detector is not required on the receiver circuit with which this Amplifier is employed.

The Amplifier is specially designed for use with a receiver working on a swinging frame coil instead of the usual aerial-earth connections; thus if the receiver is connected to a coil consisting of two or more turns of stranded cable, and about 12 ft. in diameter (or side, if a square), very strong signals will be obtained. The coil can be erected indoors and should be pivoted because the directional effect is very marked as the coil is swung round into the plane of the transmitting station. The Amplifier gives better results than a Low Frequency one on wave lengths above 1000

metres, but for reasons already explained it is not efficient on short wave lengths.

Small valves, known as the Q type and V 24 type, have been designed by Round and are employed by the Marconi Company on valve receivers and amplifiers. They will be described in a succeeding Chapter, and for the present it will be sufficient to remark that the capacity effects in these valves are smaller than those in the French valve. They are therefore more suitable for use on H.F. Amplifiers designed for short wave work.

A H.F. Amplifier designed by Round is shown diagrammatically in Fig. 62; it had four (or six) valves of the V 24 type in cascade giving high frequency amplification, followed by a Q valve to act as the final rectifier. The H.F. amplifying or ultra

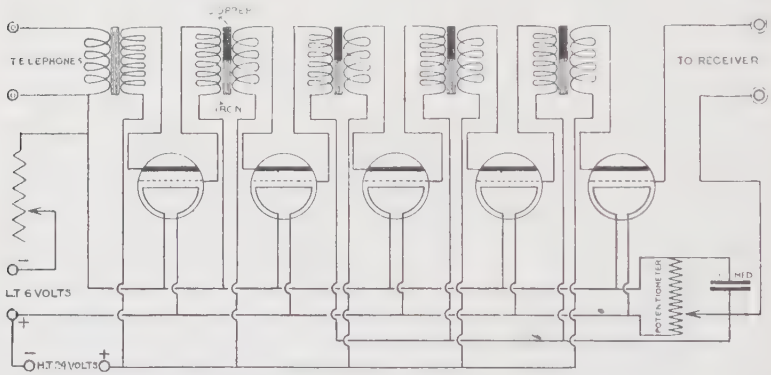


FIG. 62.

magnifying valves were interconnected by means of transformers with specially designed and adjustable cores. These cores consist partly of iron and partly of copper as shown; they were all connected to one adjusting handle by which they can be moved. Inserting the iron of the core increased the inductance effects and inserting the copper of the core increased the capacity effects of the coils; by having movable cores of this description it is possible to arrange that the amplifier gives its optimum effects at a given wave length, and the movement of the cores to some extent changes this wave length. The primary and secondary coils of the transformers were of No. 46 silk-covered copper wire wound one directly over the other.

It is seen that the grid potential of the first four amplifying valves was adjusted by means of a potentiometer to work on the

best part of the characteristic curve, and that of the Q valve was separately adjusted, or at zero potential as shown, where its rectifying properties are good.

A H.F. Amplifier of this type is most sensitive at one given frequency, or wave length, and the curve of sensitivity falls very sharply above and below this frequency. In the preceding paragraph a method employed by Round to ensure uniform sensitivity for a certain range of wave lengths has been described. In practice this method has not proved very satisfactory as the tuning is accompanied by a loss of efficiency. Experience with this amplifier has shown that not much advantage is to be gained from the iron-copper cores on long wave work, and in subsequent designs of long wave amplifiers the cores were discarded. In making the transformers it is essential to keep the capacity effect of the windings as small as possible, otherwise they neutralise the advantage of low capacity valves.

This indeed makes it difficult to design a H.F. Amplifier with transformer coupled valves for short wave working, and up to the present the problem of designing short wave H.F. Amplifiers has not been really solved. Short wave here refers to wave lengths under 200 metres, such as are employed on aircraft, the reception of which over long ranges is a matter of great importance.

The H.F. Amplifiers now made by the Marconi Company are not fitted with transformer cores of copper and iron, sensitivity being brought up by employing six ultra-magnifying valves instead of four. The amplifiers are designed for working on a definite wave length range, one being made for use on a range of 100–300 metres, another for use on 600–1200 metres, and so on. A later pattern of Marconi H.F. Amplifier is shown diagrammatically in Fig. 63. There are six ultra-magnifying valves of the V 24 type and one rectifying valve of the Q type. The heating of the filaments is regulated by a rheostat, R, and the grid potential of the first six valves by a potentiometer, P. The intervalve transformers have coils of special high resistance wire, wound on ebonite cores. The connections of the first six (V 24) valves are as shown in the Fig. for the first two.

The Q valve rectifies best when the grid is directly connected to the negative leg of the filament—therefore it is not regulated by the potentiometer. It will be noted that the transformer windings which couple the V 24 valves are interconnected by small condensers K_3, whilst the usual blocking condenser is connected across the primary of the telephone transformer.

For short wave working the terminals AB are connected across the inductance of the wireless receiver, A being connected to the aerial end and B to the earthed end. The Amplifier may also be connected across a tuned circuit coupled to the receiver aerial circuit.

The Amplifier contains a small reaction coil wound on ebonite and connected to the terminals CD; this coil slides across the end of the last intervalve transformer and the coupling between the two can be varied by a handle projecting from the side of the instrument. For C.W. reception, on wave lengths above 300, a

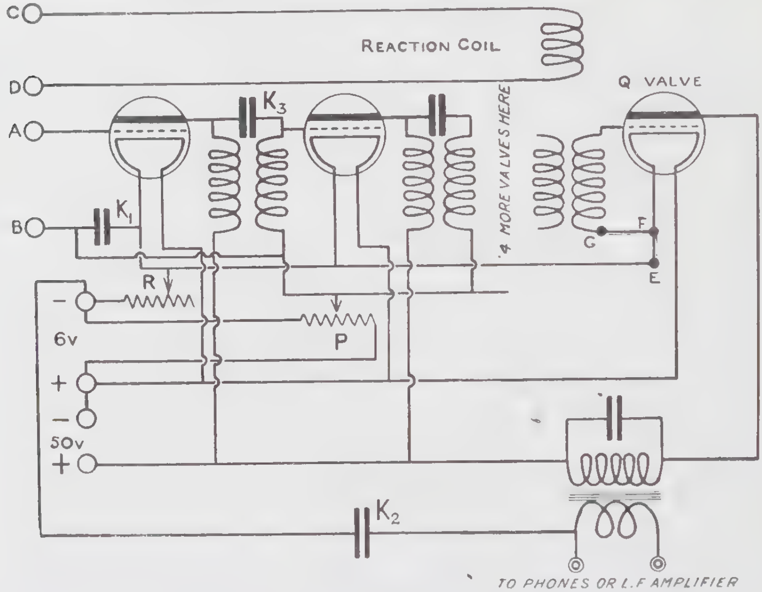


FIG. 63.

small amount of reaction is necessary to make the valves oscillate, as may be required if the amplifier has to heterodyne the signals. A small amount of reaction may also increase the amplification on long wave spark signals by bringing the valves near the limit of oscillation. On short wave working the reaction coil is not required, as the short wave instrument can be made to oscillate by a proper adjustment of the potentiometer. To bring the reaction coil into use the terminals C and B are connected together. A is connected to the aerial terminal of the receiver circuit, and D is connected to its earth terminal. This puts the reaction coil

in series with the inductance in the receiver included between its aerial and earth terminals ; thus, when the reaction coil is coupled to the sixth transformer, the plate circuit of the last ultra-magnifying valve reacts back on the aerial circuit and on the grid circuit of the first valve.

To adjust the instrument for best working the potentiometer should be adjusted before the reaction coil is pushed in ; the reaction coupling should then be set for the limit of oscillation, or for oscillating the valve circuits as required. With this amplifier it is possible to decrease jamming by strong signals, using an extra filament rheostat and a potentiometer on the rectifying, or Q, valve. To do this the link across EF is taken out and an adjustable rheostat is connected across these two points. A potentiometer wire is connected across the 6-volt filament battery, the link connecting F and G is taken out, and G is connected to the slider of the potentiometer. The jamming signals are then reduced by first increasing the resistance in series with the Q valve filament and then adjusting its potentiometer ; by this means it is often possible to cut out loud signals altogether, while the weaker signals are still strong enough to be read comfortably.

The Q valve is now acting at the saturation bend of a low voltage curve, therefore the possible extent of the plate current pulses is limited, so that strong signals are not unduly amplified.

When using the amplifier on a Bellini Tosi Compass the search coil is shunted by a variable tuning condenser and connected across the terminals AB of the amplifier ; it is also advisable to connect a small variable condenser from the terminal A to earth, and adjust this condenser until it is found that a good minimum of signals can be obtained.

The instrument is enclosed in a metal case and it is important that this case should be connected to the negative terminal of the 6-volt filament battery. A view of this Amplifier is given in Fig. 64.

As regards the small condensers, K_3, interconnecting the plate of one valve to the grid of the next, these are similar to those used in the French design of amplifier already described (see Fig. 57). In fact, if we consider the winding of the transformer in series with the plate as a resistance R, and the winding from the grid to the earth terminal B as a leak resistance r, the functioning of the instrument as an amplifier could be described in the same manner as that of the French amplifier.

The transformer windings are wound to a very high resistance,

in one case this measured 20,000 ohms for each winding, and

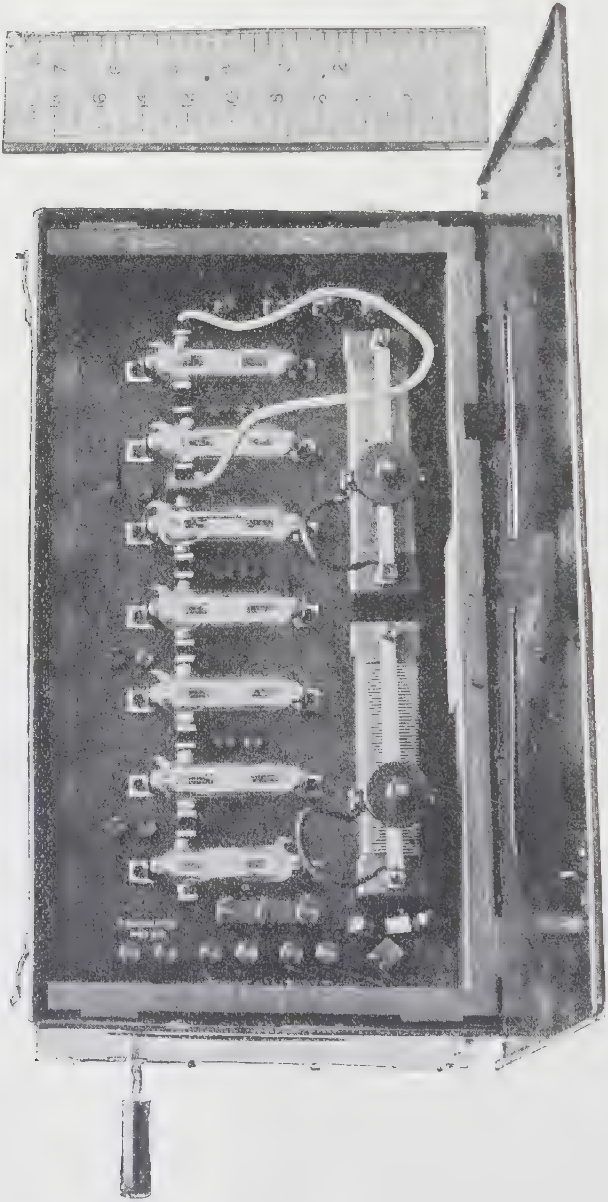


FIG. 64.—Marconi Multi-valve H.F. Amplifier and Detector. Type No. 55

in the latest form of these amplifiers special high resistance wire is used for the coils of the transformers. This gives a greater damping effect, so that the curve of strength of signals on different wave lengths is a broad one instead of being sharply peaked at a short range of wave lengths, as in the previous designs in which intervalve transformers were employed. It is possible, therefore, that the instrument would be more efficient if these resistances were made higher, especially that in the grid circuit which acts as a leak. It may be recalled here that the resistance in the plate circuit should be high compared with that between the plate and filament in the valve when functioning; the latter increases as the plate potential increases but falls if the filament temperature is raised. In the case before us, where the resistance is in the form of a transformer coil, there is an inductive change as well as an ohmic change of volts in the coil when the plate current changes, and it may be that the total effect is equal to that given by the 80,000 ohms in the plate circuit of the French amplifier. The transformer action will also aid the condenser to transfer potential change from the plate of one valve to the grid of the next, whilst the combined inductance and capacity effects of the circuits will give the instrument good sensibility over a certain small range of wave lengths. As explained before it has been found very difficult to design H.F. Amplifiers of the resistance or transformer types for efficient short wave working, the difficulty being mainly due to the capacity effects in the valves themselves. The latest design of this Amplifier is described in Chap. XVI.

The following method of employing H.F. Amplifiers on short wave signals has been tried with some success :—the signals are received on a heterodyning valve receiver, in which oscillations are generated which form beats with the received oscillations, the beat frequency being about 50,000 or more. This frequency corresponds to that of long wave signals, and if these beats are then passed into H.F. Amplifiers of one of the types here described they will be well amplified. The amplifier is designed to be most efficient at the comparatively low frequency of the beats, which corresponds with long wave length work. It is then adjusted to oscillate and form beats of audible frequency with the resultant beat oscillations passed into it from the receiver ; so that signals are obtained.

In designing and laying out the wiring of a H.F. Amplifier it is important to see that all connections are as short as possible ; made of stiff wire, and all unnecessary capacity effects eliminated.

The best type of receiver circuit on which to use the Amplifier is a tuned closed circuit loosely coupled to the aerial circuit, such as is shown in Fig. 65. Some signals will be increased by using a reacting valve as shown dotted in the Figure; this will initially amplify the high frequency oscillations in the aerial circuit, and rectification occurs earlier in the amplifier.

It is apparent that the design of High Frequency Amplifiers is still in the experimental stage; it is probable that instruments employing a great number of valves in cascade, with consequent abnormal consumption of battery current, will be replaced by new designs in which two or three valves are coupled by tuned circuits on the lines of Fig. 32.

In Chap. IV., Figs. 26 and 32, methods were given for

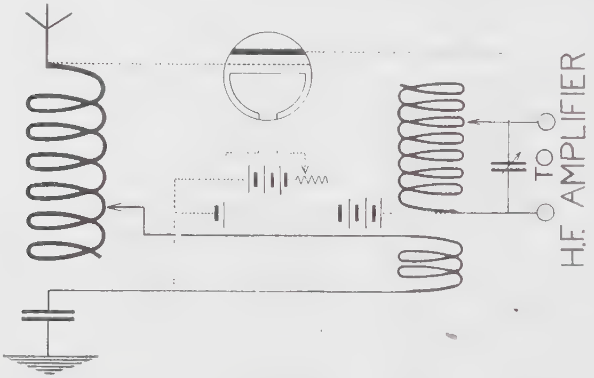


Fig. 65.

obtaining H.F. amplification by means of valves coupled by tuned circuits; one of the striking advantages of this method is its great selectivity, and the fact that jamming by strong local signals is practically eliminated, unless they happen to be dead on the wave length. Owing to the marvellous development of the sensitivity of wireless reception brought about by the perfection of valve apparatus all the efforts of designers of wireless apparatus at present are centred round the problem of minimising jamming both by signals and atmospherics. It is, therefore, worth while to consider further the resonance method of amplification, a method described and advocated by Dr. I. Langmuir early in 1915.

Referring to Fig. 26 it is apparent that a very slight coupling between the plate and grid circuits will set up oscillations in the valve itself, and in designing the apparatus this point should be

kept in mind. On the other hand, since a valve receiver is most sensitive for spark signals when it is just on the point of oscillating, it might be advantageous to arrange these circuits so that a slight coupling between them can be adjusted. It could then be used for C.W. signals by adjusting the coupling so as to make the first valve oscillate.

The plate circuit of the first valve need not include the whole of the coil S but may tap in a portion of it , this will not affect the tuning.

Similar remarks apply to the connections shown in Fig. 32, which will give sharp selectivity, and the coupling of the reaction coil in the plate circuit of the first valve can be adjustable so that oscillations may be generated and the receiver used on C.W. signals. It is probable that H.F. Amplifiers will be developed on these lines, and a little modification will make these circuits suitable for short wave working on the two-beat method, referred to in a previous paragraph.

With H.F. Amplifiers as at present constructed selectivity can be greatly aided by the use of direction finding aerials of the Bellini Tosi type, or even by the use of helices which can be oriented instead of the usual earthed aerial circuit. Further reference will be made to this in connection with C.W. receivers.

QUESTIONS ON CHAPTER VII.

1. Give a short explanation of the action of a reacting condenser between the first grid and last plate of a H.F. Amplifier.
2. Why are H.F. Amplifiers not very efficient on short wave lengths ?
3. The Marconi Co. uses a Q valve as the last valve in their H.F. Amplifier and V 24 valves in all the other positions. Explain why the valves are not all of one type.

CHAPTER VIII

HETERODYNING—SENSITIVENESS OF VALVE RECEPTION

In Chap. IV. reference has been made to the beats, or pulses, which may be set up in a valve receiver, when the reaction coupling is sufficiently tight between the plate and grid circuits and the valve itself is generating oscillations. If spark signals are being received under these conditions the note of the signals becomes hoarse or harsh and it is impossible to identify the transmitting station by the quality of its note. These beats are the result of a combination of the oscillations generated by the valve and the oscillations induced by the ether waves carrying the transmitted signals. To explain this formation of beats by the two sets of oscillations let us first assume that the transmitted ether waves are undamped, and that the oscillations induced by them in the receiver circuit are of the same amplitude as those generated in the circuit by the valve. But let the receiver circuit be slightly mistuned from the ether waves so that the oscillations generated in it by the valve are of slightly different frequency from those induced in it by the ether waves. The resultant of two such sets of oscillations of slightly different frequency, in the same circuit, will be as shown in Fig. 66.

Suppose the transmitted signals have a frequency of f_1 and the valve oscillations a frequency of f_2; the latter frequency can be easily adjusted to any value by tuning the circuit of the receiver, and therefore can be arranged to be a little more or a little less than that of the received impulses. We have then two sets of oscillations in the valve receiver, one set up by the distant transmitting station, the other generated by the valve itself. In Fig. 66 the frequency f_2 is shown a little less than that of f_1; by adding the two oscillating effects when they act together (either above or below the line AB), and taking their differences when they act in opposition the full line wave in Fig. 66 is obtained ;

this represents the resultant oscillating effect in the receiver circuits. It amounts to a series of oscillations of uniform frequency, $\frac{f_1+f_2}{2}$, but of varying amplitudes, giving pulses or beats of energy which die away (from A to C) and rise again (from C to D) at a frequency equal to (f_1-f_2). If the valve is functioning at a rectifying point on its curve the resultant oscillations, of frequency $\frac{f_1+f_2}{2}$, will be rectified and thus unidirectional pulses of frequency (f_1-f_2) will act on the telephone receivers in its circuit.

Thus, suppose transmission is taking place on a 600 metre wave length: this will induce oscillations in the receiver at a frequency (f_1) of 500,000 per second. If the valve is generating oscillations at a frequency (f_2) of 499,000 oscillations per second the

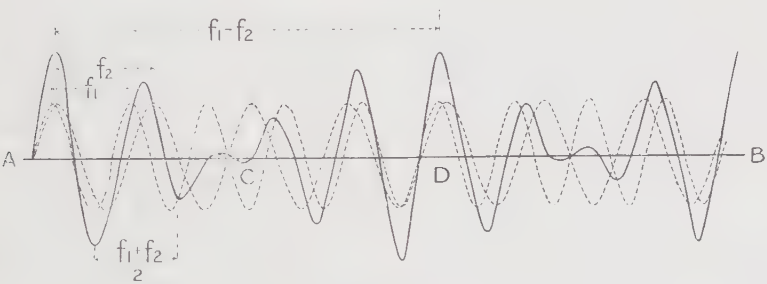


FIG. 66.

beats will have a frequency of 1000; or if the valve generates oscillations at a frequency of 501,000 the same result will be obtained.

In continuous wave reception where the received oscillations are uniform in amplitude, not forming trains of oscillations as in spark signalling, this use of a valve is one of the principal methods of breaking up the oscillations into groups, so that low frequency pulses or beats act on the telephone receivers and give a musical note. It is seen that by the tuning of the valve receiver circuit the frequency of the beat can be made 1000, 800, 600 or anything desired, so that the pitch of the note heard in the telephones may be adjusted to any desired valve. If the difference between the frequencies of the received and valve generated oscillations is too great the beats will be inaudible, because the beat frequency is too high; similarly if (f_1-f_2) has too low a value the beats will

again be inaudible because their frequency is too low. Thus in the reception of undamped waves, or C.W. signals, the tuning of the valve receiver circuit must be adjusted with good accuracy, especially on comparatively short wave lengths. For example, if it is desired to receive signals transmitted on a 600 metre wave length, whose frequency is 500,000, by forming beats of 1000 frequency, the oscillating valve receiver must be tuned to a frequency of 499,000 or 501,000. If 501,000 is chosen it means that the receiver circuit is tuned to a wave length of 598·8 metres, since $\lambda \times f = 3 \times 10^3$. Thus, to hear the signals on a good note, of 1000 frequency, the receiver must be tuned to within 0·2 per cent. of the frequency of the incident waves.

The longer the wave length of transmission the greater will be the tuning range on the receiver which will give audible signals. This is because long waves correspond to low frequencies, and the lower the frequency the greater is the percentage difference of frequency which gives a beat of a certain pitch. Thus if the wave length is 12,000 metres the frequency is 25,000; to form a beat of 1000 frequency the valve receiver will be tuned to, say, 24,000 frequency, *i.e.* to a wave length of 12,500 metres or a difference of tuning in this case of 4·17 per cent.

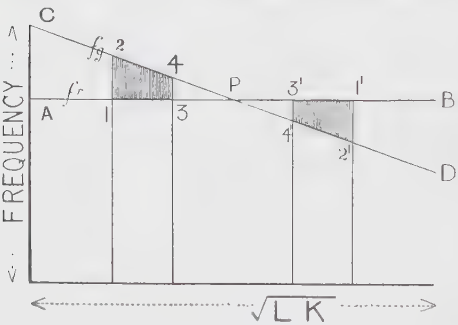


FIG. 67.

The ranges of tuning which will give audible and inaudible beats can be shown by means of a diagram. Thus in Fig. 67 suppose the line AB represents the steady value of the oscillation frequency set up by the received ether waves, and CD the frequency of the oscillations generated in the receiver as its oscillation constant $\sqrt{LK}$ is varied. When the frequencies differ by the amount 1 2 an audible and very high beat note will be formed; this note will decrease in pitch as the difference of frequencies, *i.e* the beat frequency, falls until it is down to the value 3–4. Beyond this the difference of frequency is not sufficient to make an audible beat until the difference of frequency is again audible at 3′–4′; a second range of audible beats is then heard between

3′–4′ and 1′–2′; beyond 1′–2′ the note again has too high a frequency to be audible.

Thus in the beat method of receiving signals on undamped waves there are two ranges of tuning on the receiver at which the signals will be audible; within these ranges the receiver can be adjusted to give signals of different note pitch, and between these ranges no signals are heard.

It is important in continuous wave work to note that the generated and received oscillations are only exactly in tune at the point P where $(f_1 - f_2) = 0$ and there is no beat; this is generally called the *silent point*. Fig. 67 is not drawn to scale, and the range of silence from 3–4 to 3′–4′ is comparatively much less than there shown. The longer the wave length, or the lower the frequencies, the greater will be the ranges of audibility, and the wider will be the silent point as $\sqrt{LK}$ is varied by tuning the receiver either by a variable condenser or by a variometer. The range of audibility on the variable tuning condenser depends on the percentage change of tuning made by a difference of 1° on the condenser; the smaller the maximum value of the condenser the greater the audible range on its scale. There is no silent point when spark signals are heterodyned because, no matter how sharp the tuning of a spark transmitter, the radiation does not occur on one pure wave length, therefore oscillations of different frequencies are induced in the receiver, with one or more of which the valve oscillations will form beats when its circuit is tuned for reception.

The reception of signals by the formation of beats between the received and local oscillations is known as the *Heterodyne* method. It is the most efficient for undamped waves, *i.e.* for C.W. work. It is a disadvantage to heterodyne spark signals at the receiver since the pure note of the transmitting station is thus obliterated; at times, however, when the signals are weak it may happen that, to make them readable, the reaction coupling has to be made so tight for amplification that the valve starts generating oscillations. If the transmitting station is recognised by its call, or by momentarily loosening the reaction coupling to stop the valve generating so that the pure note of the transmitting station is heard, the disadvantage is only apparent, and the amplification given by tighter reaction can be employed even though the signals are heterodyned.

In explaining the formation of beats, as illustrated in Fig. 66, it was assumed that the amplitudes of the two sets of fundamental oscillations were uniform and equal; a little consideration will

show that these conditions are not necessary. In spark signals the amplitude of the oscillations induced in the receiver aerial varies during each wave train, or spark, but these oscillations will combine with the uniform, or undamped, local oscillations to form beats. Again, in the general case, the local oscillations will be stronger than those induced by the ether waves; therefore the amplitude of the resultant oscillations will never be zero. The beat, when rectified and smoothed out, will be like a steady current in the circuit with pulses of increase of current impressed on it, rather than pulses of current starting from zero as in the case shown in Fig. 66. In the calculations on beat reception given later it is not assumed that the local and received oscillations are of equal amplitude.

Auto-Heterodyning and Ultra-Heterodyning.—There are two methods of heterodyning or forming beats in a wireless receiver; in the first a valve is employed as a detector-relay on the circuit and at the same time it is made to generate oscillations by having an induction coupling between its plate and grid circuits. This method is generally known as the *Auto-heterodyne* or *Autodyne* method; the generation of oscillations by a valve under these conditions has been already dealt with in Chap. V. under the heading "Oscillating Circuit on the Grid."

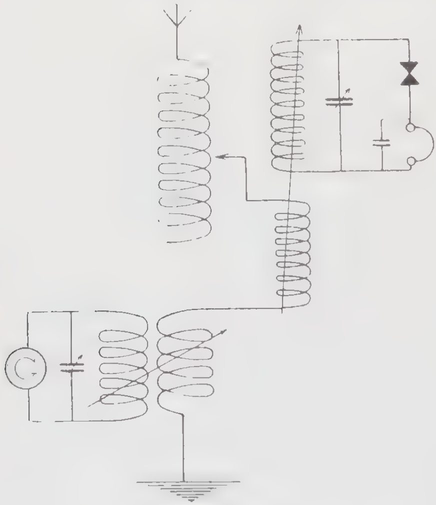


Fig. 68.

In the second method of heterodyning the local oscillations are set up in the receiver by coupling it to an oscillating circuit quite independent of the receiver circuits. This method is known as the *Ultra-heterodyne* or *separate* heterodyne method; with it a crystal detector or a non-oscillating valve may be used for rectification.

Thus a circuit may be made up as shown in Fig. 68; a small local oscillator at G is coupled by a tunable circuit to the aerial.

The oscillations induced by it in the receiver circuit and those induced by the incident waves from beats which are rectified by the crystal detector. The local generator of oscillations may be a buzzer wavemeter, or it may be an oscillating valve circuit in the vicinity of the aerial circuit; also it may be coupled to any of the receiver circuits.

The reception of signals by this method of heterodyning was the subject of U.S. patents granted to Fessenden in March, 1907, and there are still certain advantages in having a local oscillator other than the valve which is used for rectification, and perhaps for amplification simultaneously, on the receiver circuit. In the first place if a valve is to amplify as well as rectify there must be a reaction between its plate and grid circuits; if at the same time it is to generate oscillations the reaction coupling must be made closer than for amplification alone, in which case signals not in tune will be amplified and jamming will be prevalent. With an independent local oscillator C.W. reception can take place with very loosely coupled circuits, tuning will be much sharper, and jamming reduced. Those who have handled C.W. traffic will appreciate the great advantage of any method which cuts out spark jamming.

Again in the auto-heterodyne method the receiver circuit must be slightly mistuned from the incident ether waves in order that the oscillations generated by the valve may differ in frequency from those induced by the ether waves. This mistuning reduces the amplitude of the oscillations set up by the incident ether waves, and reduces the sensitiveness of the receiver, especially to very weak signals.

With an ultra-heterodyne the receiver circuit, having perhaps a valve detector amplifying by reaction, can be set sharply in tune with the incident ether waves, and the resulting induced oscillations will be of maximum strength. The local oscillator will be slightly out of tune but the amplitude of the oscillations induced by it in the receiver can be adjusted by adjusting the coupling between them. The valve on the receiver, if a reacting one, can be adjusted to be just on the point of oscillating—its frequency being that of the ether waves to which the receiver is tuned. Under these conditions it has been shown in Chap. V. that the ohmic resistance of the receiver circuit to oscillations of this frequency is greatly reduced if not entirely wiped out; the receiver is then in the most sensitive condition and will respond well to the induction effect of weak ether strains at that frequency. This

negative resistance effect will be referred to again in a later section.

Lastly, when an independent heterodyning arrangement is employed it can be calibrated in wave lengths so that it may be used, like a wavemeter, to set the adjustments of the receiver circuit with fair accuracy.

With continuous waves the range of signalling is very much greater than with spark methods; signalling on comparatively long wave lengths may be carried out with short low aerials, and transmission can take place over long ranges from aerials which do not issue from the building in which the transmitter is installed. No doubt this is partly due to the undamped radiation, but the comparatively great ranges of C.W. are largely due to the amplifying effects which may accompany beat reception, some of which have been referred to above.

Let us now consider in detail why heterodyne reception should be so sensitive compared to other methods. Referring again to Fig. 66 it will be seen that the maximum amplitude of the beats in the receiver circuit is greater than that of the oscillations set up by the ether waves; it is also apparent that the difference between the maximum and minimum amplitudes of the beats is greater than the amplitude of the received oscillations.

When a crystal detector is employed on ordinary spark reception the signal strength in the telephones is proportional to the square of the mean amplitude of oscillation set up in the receiver. With a reacting valve detector, or other heterodyning arrangement, the oscillating energy in the receiver circuit is amplified by a factor which is due to the local oscillations.

B. Liebowitz [1] pointed out that if I_r and I_l are the effective values of the oscillating currents in the receiver circuits, due to received and local oscillations respectively, and L is the inductance of the circuit, the average energy $(W_m) = \frac{1}{2}LI_r^2 + \frac{1}{2}LI_l^2$. This does not mean that the more current induced in the circuit by the local, or heterodyning, oscillator the greater will be the pulsing energy for producing signals in the telephone receivers; a little consideration of Fig. 66 will show that if the local and received oscillations are unequal there will be a steady component, and the low frequency beat current does not fall to zero value.

Considering the matter from another point of view, if A sin pt is the instantaneous value of what we might call the local

[1] *Proceedings of Institute of Radio Engineers*, June, 1915.

oscillations and B sin $(p+\beta)t$ that of the received oscillations, the resulting current at any moment is :—

$$\begin{aligned} A \sin pt + B \sin (p+\beta)t &= (A + B \cos \beta t) \sin pt + B \sin \beta t \cos pt \\ &= \sqrt{A^2 + B^2 + 2AB \cos \beta t} \times \sin (pt+\phi) \end{aligned}$$

where $\phi = \tan^{-1} \dfrac{B \sin \beta t}{A + B \cos \beta t}$

This represents a current of variable amplitude and phase, of frequency $\frac{\beta}{2\pi}$, equal to the difference of the frequencies of the two currents.

The maximum value of the radical is $\sqrt{A^2 + B^2 + 2AB}$ when $\beta t = 2n\pi$ and the minimum value is $\sqrt{A^2 + B^2 - 2AB}$ when $\beta t = (2n + 1)$: n being any positive integer. Thus the maximum amplitude is $(A + B)$ and its square is $A^2 + B^2 + 2AB$; the minimum amplitude is $(A - B)$ and its square is $A^2 + B^2 - 2AB$. If the local oscillator is a separate circuit coupled to the receiver, and an ordinary crystal detector is used on the latter, the loudness of signals will depend upon half the difference of the squares of the maximum and minimum amplitudes ; that is to say, on 2AB, therefore it is qualified by the local oscillations which may be stronger than the received ones.

With ordinary crystal reception of spark signals the loudness of signals in the telephones will be proportional to $\frac{1}{2}B^2$, and it is easily seen that 2AB can be much greater than $\frac{B^2}{2}$. For a similar reason the heterodyne method of reception of undamped waves is much more sensitive than the " tikker " method which had been formerly employed. Also, this explanation does not take into account the negative resistance effect which may accompany the action of heterodyning and will give further amplification of signal strength.

The effect of the local oscillator is very similar to that of the permanent magnet on which the coils of telephone receivers are wound ; this effect was explained in Chap. III., where it was shown that the magnet produced a constant flux through the coils but also provided a factor by which the effect of a pulsing current was multiplied. In a similar manner the local oscillator of a heterodyne, combining with the received oscillations, produces in the general case a steady component of current and a multiplying factor for increasing the pulsing component.

The steady or sustained component (of the resultant of the two sets of unequal oscillations) may make the receiver more efficient by increasing the magnetic flux in the poles of the telephone receivers, and thus increasing their sensitiveness. However, this effect is limited by the saturation of the vibrating diaphragm or reed, so that for this reason, if for no other, a proper adjustment of the strength of the local oscillations is necessary.

In practice it is generally found that the maximum strength of signals is not given by equal amplitudes of the received and local oscillations, a condition which is called "*equal heterodyne.*" To explain why the best signal strength is obtained when one set of oscillations is stronger than the other, Edwin H. Armstrong refers to the effect on the grid circuit current. Suppose the curve of grid current is as shown in Fig. 69; the valve will then be functioning at some point such as A on the grid current curve. Let the effect of the local oscillations change the grid potential by v volts and the effect of the received oscillations also change it by v volts, then at each signal the grid current pulse is from B to C, for the maximum amplitude of the beat cannot be greater than the sum of the component amplitudes. This pulse of grid current will be accompanied by a corresponding pulse on the plate current curve.

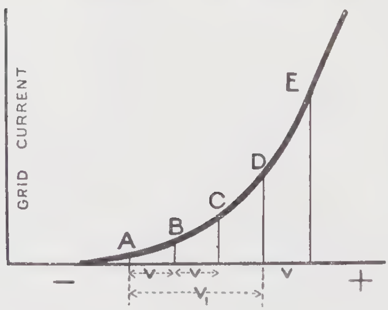


Fig. 69.

If, however, each positive half of a local oscillation changes the grid potential by v_1 and that of a received oscillation changes it by v, then the grid current changes from D to E on the curve when a signal arrives. This change is on the steep part of the curve and is therefore much greater than the change from B to C given by equal heterodyne, it is accompanied by a corresponding pulse of current in the plate circuit.

If the grid is connected in series with a leaky condenser its potential does not rise when the leak has a sufficiently high value, but the pulses of negative potential on the grid will depend on the values of the current which charges it, and these values depend on the positive halves of potential oscillations induced in the grid circuit. Thus with this arrangement also the best effects

are obtained when the local oscillations are stronger than the received ones.

The beat or heterodyne method of reception is also efficient because the beat note can be made fairly high, nearer the natural vibration frequency of the telephone diaphragm, or nearer the frequency at which the human ear is most sensitive. It may also be adjusted at will to a pitch which may make it easy to read through jamming, whereas the pitch of a spark note in ordinary crystal reception is fixed.

Now let us consider the case of beat reception of undamped oscillations (C.W.) with a valve rectifier, and the further advantages which may thus accrue. In Chap. III. it has been shown that if dv is an oscillation amplitude of the grid potential of a valve the corresponding pulse of plate current, and therefore the strength of signal, is proportional to $\frac{dv^2}{2}f''(v)$. The case of heterodyne reception has been dealt with by Prof. Gutton as follows: –

When beats are set up the change of grid potential dv is the sum of two oscillating potentials, dv_1 and dv_2, which are very near each other in frequency so that $dv = dv_1 + dv_2$ approx.

Thus
$$\frac{dv}{2}f''(v) = \frac{(dv_1 + dv_2)^2}{2}f''v$$
$$= \frac{dv_1{}^2}{2}f''(v) + \frac{dv_2{}^2}{2}f''(v) + dv_1 dv_2 f''(v)$$

Now the first two terms on the right-hand side of this equation are constant, since they correspond to two individual sets of undamped oscillations, while the third term, $dv_1 dv_2 f''(v)$, changes its sign as the two sets of oscillations go in and out of synchronism. Therefore the first two terms represent a sustained component of grid potential in the rectifying valve when signals are coming in, and the third term a pulsing component. We therefore get a sustained change of plate current plus a pulsing change. For spark reception with simple valve rectification the pulse set up in the plate current is proportional to $\frac{dv^2}{2}f''(v)$, therefore to the square of the amplitude of induced oscillations acting on the grid; for C.W. signals heterodyned the pulse of plate current is proportional to $dv_1 dv_2 f''(v)$, therefore proportional to the first power of the induced oscillations. Also it is seen that if dv_1, *i.e.* the oscillation of potential induced by the ether waves, is very small

$dv_1 \times dv_2$ can be much greater than dv_1^2. For this reason alone beat reception of undamped waves by a valve can be successful over great ranges compared to the reception of damped waves or spark signals.

Again it will be remembered that a valve rectifies well at the point on its characteristic curve where grid current starts. If the grid potential is less than that corresponding to this point the plate current, through the plate circuit battery, will be small. With beat reception it is possible to adjust the grid potential to a point lower than the rectifying point and where the plate current is small; when signals arrive the sustained component of the heterodyne effect will bring the grid potential up to the rectifying point, and the pulsing component will then produce the signals. This leads to economy of plate battery current.

Lastly, it has been explained in Chap. V. that if the plate circuit of a valve is made to react on a tuned grid circuit, so as to generate oscillations, the effect is to wipe out the resistance of the tuned circuit to oscillations of the given frequency. Under these conditions weak ether wave effects at that frequency will build up oscillations in the circuit of larger amplitude than would otherwise be the case. Therefore this effect gives a further addition to the sensitivity of the heterodyne method of reception; it can indeed be elaborated so that a receiving circuit may be made sensitive only to one particular frequency, thereby eliminating interference and jamming. A circuit patented by Pupin and Armstrong and designed to effect this purpose will be described in a later Chapter.

It is apparent from the foregoing explanations that the comparatively great ranges possible with C.W. working are due more to the advantageous conditions at the heterodyning valve receiver than to the fact that the energy radiated from the transmitter is undamped. Indeed it will generally be found that the undamped radiation from the transmitter is discounted by the employment of smaller transmitter energy, and aerial current, than would be used for spark signalling over the same range.

An interesting demonstration of the formation of "Beats" can be made by an arrangement of valves as shown in Fig. 70.

Valve A has its plate and grid circuits made up through the primary (P) and secondary (S) of a small telephone transformer T_1 with iron core, and 6 volts are applied to the filament, with anything from 10 to 50 volts in the plate circuit. A variable condenser of 0·002 mfd. maximum value is connected across from

plate to grid. Under these conditions the valve will oscillate with audible frequency. A pair of telephone receivers are connected to a telephone transformer T_3 which is then placed close to T_1 and the note is strongly heard in the receivers; the pitch of the note can be varied by varying the value of the condenser.

A second valve, B, has its circuit made up exactly similar

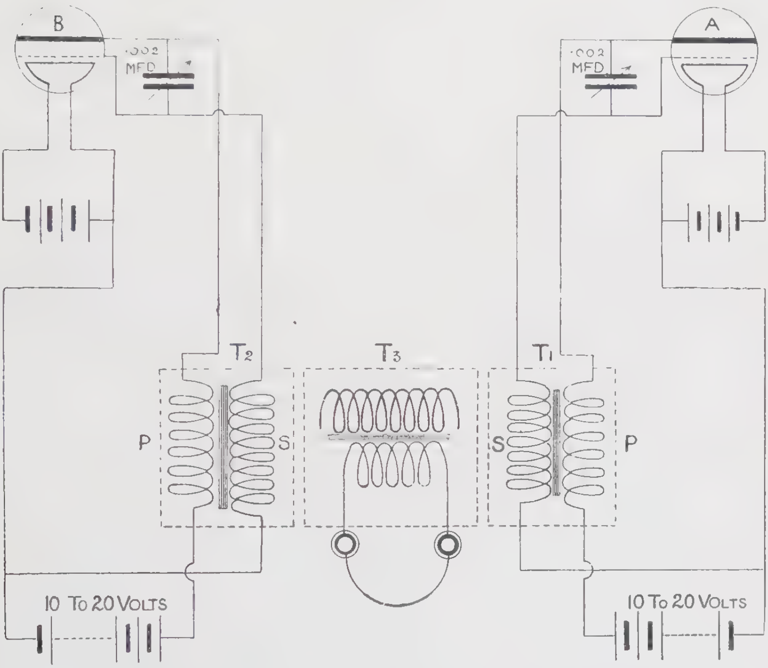


Fig. 70.

to that of A and is similarly coupled to T_3, when its oscillation note will also be heard in the receivers.

By manipulating one or both of the condensers the frequencies of the two valves can be so arranged that beats are formed which are distinctly heard in the receivers. A slight adjustment of one of the condensers will vary the pitch of the beat, and it can be wiped out altogether by making the valves oscillate at exactly the same frequency, *i.e.* give out the same note, or by making them oscillate at such widely different frequencies that the pitch of the resulting beat is too high for audibility.

Care must be taken to ensure that the transformer coils are

connected up the right way round to each grid and plate, otherwise the valve will not oscillate; this can be quickly ascertained by trial and error.

QUESTIONS ON CHAPTER VIII.

1. Why does short wave C.W. working require sharper tuning at the receiver than long wave working ?

2. What is meant by the "Silent Point" in beat reception ? How would you design a circuit to reproduce it distinctly ?

3. Give a short explanation of the difference between auto-heterodyne and separate heterodyne reception. Which is the best as regards selectivity, and why ?

4. To what extent is the strength of the received signals dependent on the strength of the local oscillations in the separate heterodyne method of C.W. reception ?

5. Explain why the heterodyne method of reception is more sensitive than other methods, such as the use of a "tikker."

6. Give several reasons why the ranges of signalling are much greater with undamped waves than with damped waves, using the same input of primary energy at the transmitter in each case.

CHAPTER IX

STUDY OF THE CHARACTERISTICS OF A FRENCH VALVE—HARMONICS

THE design of Pliotron known as the French valve is shown in Fig. 71; it has a tungsten filament 2·1 cms. long, surrounded by a grid which consists of a helix of nickel or molybdenite wire, beyond which is a cylindrical sheet plate of nickel. The valve was made up in two types, known respectively as the "S" type and "Metal" type. In the S type the grid is 1·6 cms. long and 0·45 cm. diameter and consists of 12 spirals; the grid wire being 0·02 cm. diameter. The plate is 1·5 cms. long and 1 cm. diameter. In the Metal type the grid wire is slightly thicker and there are only 11 spirals spaced slightly farther apart than in the S type.

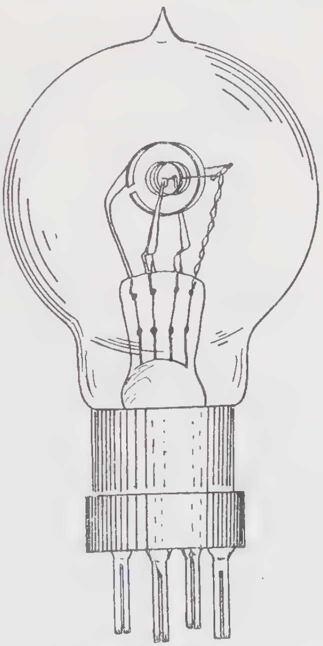


FIG. 71.

The normal filament voltage is 4 volts, but 5 or 6 volts may be used when it is desired to employ the valve in a small C.W. transmitter; the extra voltage will, however, shorten the life of the valve.

The valve is very stable and uniform in action, therefore it may conveniently be used here as a standard hard valve for the comparison of other designs. In this Chapter its characteristics will be dealt with experimentally, also an investigation will be made on the modifications of its characteristic curve under oscillating conditions.

Characteristic Curves when Oscillating.—When the valve is oscillating the characteristic curves under fixed condition of plate and filament potential will not be as hitherto described; to note the difference let a circuit be made up as shown in Fig. 72. The potential of the grid with respect to the filament can be brought to various positive or negative values by means of the battery B, fitted with a multiple-contact switch, and connected to the grid circuit through a reversing switch S_2: otherwise the circuit is that of a simple valve receiver with reaction coupling. Milliammeters M_1 and M_2 are used so that the average values of the grid

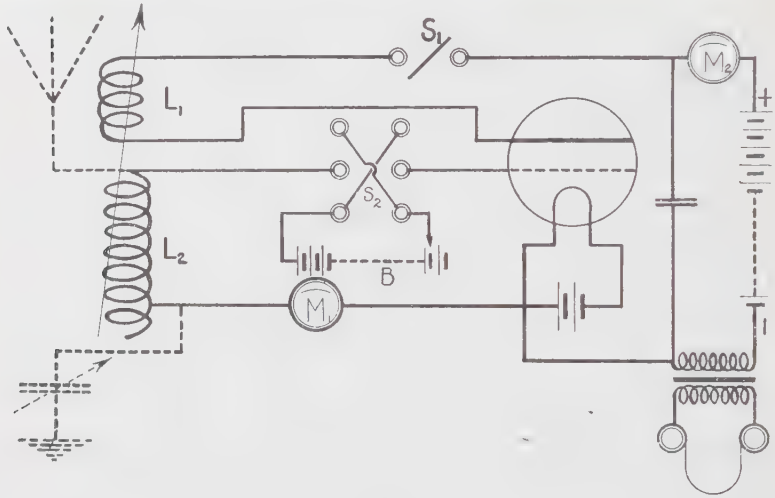


FIG. 72.

and plate currents may be noted. For the first determinations the aerial circuit, shown dotted, is not connected up, and the inductances L_1 and L_2 are so designed that about 50 per cent. degree of coupling can be used.

The characteristic curves are then obtained in the usual manner, readings of the plate and grid currents being taken at each value of grid potential under the two conditions: (*a*) with no reaction coupling, (*b*) with close reaction coupling.

The results obtained for a French S type valve with a plate potential of 75 volts, and for different filament temperatures are shown in Fig. 73. Referring to one of the curves, say that corresponding to 3·75 volts on the filament, when the valve is not

oscillating the ordinary curve of plate current A is obtained; when the reaction is coupled the curve becomes that shown at B. The corresponding curves for grid current are A′ and B′ respectively. The valve does not oscillate on the lower flat portion of the curve beyond —10·8 volts on the grid. Here the plate current is small, so that when it is started, or the reaction coupled, the inductive effect on the grid circuit is not sufficient to raise the grid to a potential at which current will flow in the grid circuit; therefore the oscillations will not be sustained by fresh impulses of energy from the H.T. battery.

Again the valve does not oscillate on the upper flat portion of the curve where the plate current is at saturation; on this part of the curve a change of grid volts does not start a change of plate current, hence oscillations are not set up.

If the valve is functioning near the lower end of the sloping part of its curve, for example at the point corresponding to —8 volts grid potential, on making a close reaction coupling the current oscillates and the average value of plate current rises from 0·6 to 2·2 milliamperes. It shows that at this point the lower half of a complete oscillation has a much smaller amplitude than the upper half, in fact the oscillations are almost completely rectified. Here a rise of grid potential increases the plate current (and gives an impulse to the circuit as already described), but an increase of the already existing negative potential on the grid makes little change in the plate current, as it soon arrives at the lower flat portion of the curve.

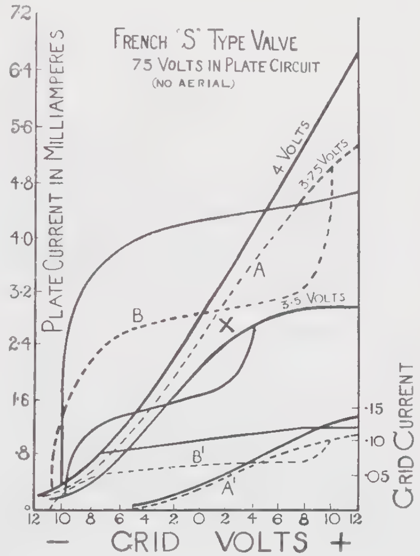


FIG. 73.

In passing it may be noted that best heterodyning effects both for spark and C.W. signals are obtained when the valve functions at this part of its curve, where the plate current is still small and the valve generated oscillations almost completely rectified. It is

in fact a rectifying point on the valve characteristic, and rectification is necessary, even with beat reception.

As the steady potential impressed on the grid is raised this dissymmetry of the valve oscillations gradually falls off until the point X is reached, corresponding in this case to a grid potential of +1 volt. Here the average value of the plate current remains the same whether the reaction is close coupled or not acting, *i.e.* whether the valve is oscillating or not. It is evident that at this point the plate current oscillations are symmetrical about their mean value; also that this is the only point, under the conditions shown of voltages applied, at which the current can oscillate with a true sine wave. With tight coupling, however, it is probable that in many practical cases the oscillations will rise and fall, about the mean value at X, to the upper and lower flat portions of the curve. If this happens the oscillation wave will be flat topped, and the fundamental oscillation will be accompanied by a third harmonic; as previously remarked there are generally other harmonics present. No signals can be received when the value is functioning at this point since there is no rectification effect.

For higher values of grid voltages it is seen that the value of plate circuit current decreases when the valve oscillates with close reaction coupling. Here an induced rise of grid voltage brings the plate current to saturation; thus the positive half of an oscillation is flattened down so that again partial rectification occurs. Near the saturation bend the valve ceases to oscillate as already explained.

When the adjustments of a receiver are varied so that the valve passes from a non-oscillating to an oscillating condition *a click is heard in the telephones owing to the change of the mean value of the plate current.*

The curves show that the point at which the oscillations of the valve are symmetrical is approximately at the middle of the sloping part of each curve, and that for any plate potential the grid voltage which gives symmetrical oscillation depends on the heating of the filament. Also the saturation value of plate current under any conditions of potential is about double the value at the point where the oscillating characteristic crosses the non-oscillating one, the characteristics being obtained with a minimum of capacity effect in the valve circuits.

Effect of Changing the Plate Potential.—If the filament temperature is kept constant whilst the plate potential is varied the

experimental results obtained will be as shown in Fig. 74. As the plate volts are raised the characteristic curve rises more steeply and moves towards the left, the oscillating component of current increases, and beyond 100 volts the point of symmetrical oscillation moves towards the region of negative potential on the grid. This is important in C.W. valve transmission and will be referred

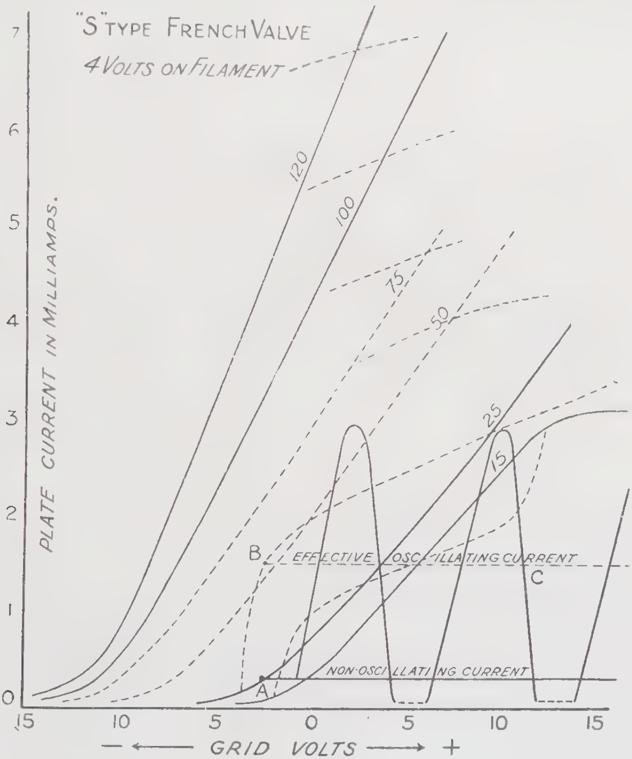


FIG. 74.

to later. As far as reception is concerned the curves corresponding to 15 volts, 25 volts, and 50 volts are more interesting.

On these it is seen that, with zero or negative grid potential, the valve oscillations are always more or less rectified and the amplitude of the oscillations depends on the plate voltage. Since the valve is generally required to rectify, as well as amplify and perhaps heterodyne, the received signals it must function near the bend of its curve with negative grid potential; Fig. 74 shows

that for all working voltages this is the point at which maximum rectification of its own oscillations also takes place, supposing the reaction coupling to be so close that it does oscillate.

Thus with no reaction coupling the valve is functioning at the point A on the 25 volt curve; when the reaction is made close the valve oscillates and the average value of the plate current goes up from A to B, so that the nature of the resulting oscillation must be somewhat as shown in the Figure at C, neglecting harmonics.

The grid current will pulsate at the same time and in much the same manner, but the potential at which its oscillations are symmetrical does not coincide with that which gives symmetrical oscillations in the plate current, since for negative grid potentials one half of the grid current wave will be absent. Its value will move to the right as the plate potential is increased, the amplitude of the oscillations increasing at the same time; this is to be expected since a higher plate potential means that there is a larger plate current to produce inductive voltages on the grid circuit.

As already mentioned the amplitude of the oscillations will depend upon the shape of the characteristic curve of the valve, being greater as the curve is steeper. This really amounts to saying that the oscillating properties depend upon the design of the valve, especially on the hardness of the vacuum, and on the distances from grid to filament and from filament to plate.

Thus a Round C.W. transmission valve, designed to stand high voltages and of a size to deal with larger energy than the ordinary French valve, would have very poor characteristics on 75 volts or even on 200 volts plate potential, and is therefore of little value for reception purposes. Its plate is too far away from the grid and filament to give good curves on these plate potentials.

Effect of Loading with Aerial or other Capacity.—As already stated in Chap. IV., when an aerial circuit is connected across the grid coil the generated oscillations are reduced in amplitude owing to the increased capacity effects. This is easily noted in ordinary practice, for when there is fairly close reaction coupling a disconnection of the aerial circuit will start the valve yowling, this being the result of strong oscillations. For heterodyning spark or C.W. signals by means of a valve it would follow that the larger the aerial the higher the plate volts required, other things being constant. The above considerations are illustrated by the curves shown in Fig. 75; these curves were taken with a French S Type valve, a French Metal Type valve, and one experimental

transmission valve of the hard vacuum type about double the size of the other two.

The curves were taken on a circuit similar to that shown in Fig. 72, curve A_1 being the characteristic of a S type valve under non-oscillating conditions; A_2 the characteristic with close reaction coupling between the tuned grid and plate circuits and without an aerial circuit. Curve A_3 was taken under similar conditions to A_2 but with an aerial circuit connected to the grid coil, the aerial being a long high single wire with series condenser

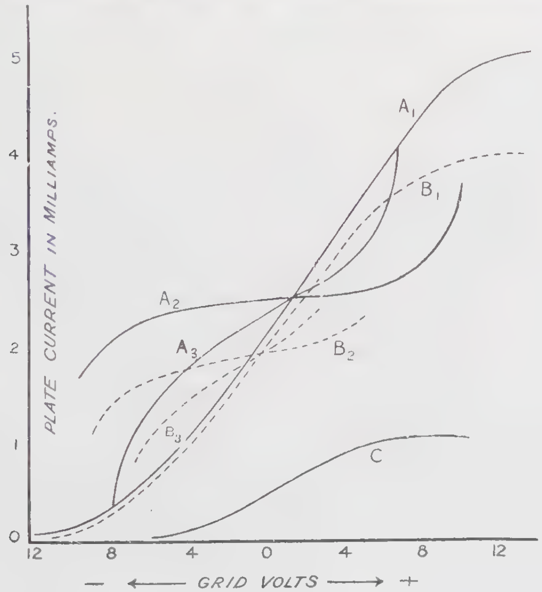


FIG. 75.

set at 0·0002 mfd. so that all circuits were in tune. This brings out clearly the effect of the aerial circuit in decreasing the amplitude of the valve oscillations. The point where the oscillations are symmetrical, or can be a sine wave without rectification, remains the same whether the circuit is loaded with capacity or not.

B_1, B_2, and B_3 are the corresponding curves for a Metal type valve; the slope of its curve is similar to that of the S type and it has, therefore, equal rectifying properties; though its oscillations are not so strong as those of the S type, they are quite strong enough to form beats with weak induced oscillations, and thus heterodyne spark or C.W. signals satisfactorily.

In fact the smaller amplitude of its oscillations will tend to prevent beats of hissing audibility in its own circuits, and allow of clearer reception of signals. For the same reason it will be more satisfactory for use on low frequency amplifiers, its relaying action being about the same as that of the S type, since the slopes of the two curves A_1 and B_1 are approximately equal.

The lower curve C is that of an experimental valve which was designed with a very hard vacuum and an open helix plate, for use on C.W. transmission with plate voltages up to 1500. Its curve is shown here, in comparison with those of the French valves, to emphasise the fact that a valve designed to handle comparatively large oscillating energy on high voltages cannot be expected to function on a receiving circuit, and will not oscillate at all on low voltages.

The characteristic curve of this valve taken with 6 volts on the filament, instead of 4, was found to lie above the curve A_1 on Fig. 75, but it was not so steep and had not a well-defined bend at the bottom of the curve.

With regard to the French valves there is very little difference in the characteristics of the S type and the Metal type; in some tests the positions of the curves A_1 and B_1 in Fig. 75 are reversed, but as a general rule the curves shown are typical of the comparison between these two types, the slight difference being due to the more open and heavier type grid in the Metal valve, and probably partly due to a difference in the hardness of the vacuum.

The frequency of the valve oscillations is approximately the frequency of the grid circuit provided its capacity preponderates over that of the plate circuit; this will be the case with the usual connection for reception, where the aerial earth circuit is coupled to the grid circuit and the reacting coil is in the plate circuit.

Characteristic Curves of Valves in Parallel.—When two valves are connected in parallel the resulting characteristic curve is the sum of the characteristics of the two valves. This is shown in Fig. 76, the curves in which were taken from an experiment with two French valves (Metal type). The curves show that with any plate potential two valves in parallel provide greater oscillating energy than when one valve alone is used, or that a certain oscillating energy is given with less plate voltage. There is not much gain in electrical efficiency by this use of two valves —more filament current is used and less H.T. battery volts required. The curve of the two valves in parallel rises at a

greater angle than that of one alone: in reception work this means better rectifying properties as well as better oscillating properties: in fact the curves show that with two valves in parallel better results are likely to be obtained with 25 volts on the plates than with 50 volts on the plate of one valve used alone. If the plate volts are kept the same for the two valves in parallel as for one valve it may be necessary to increase the negative potential on the grid by a small amount, since the curve moves a little over to the left. Another point to remember is that, with two filaments in parallel, the heating current is doubled and the drop of volts in the leads and battery increased. Therefore unless the filament voltage and temperature are adjusted to be the same for the two parallel valves as for one valve no advantage may be gained.

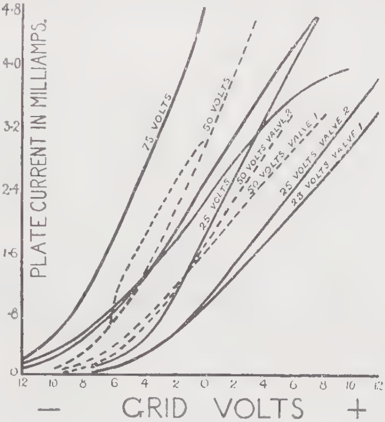


Fig. 76.

Referring to the curve of Fig. 76 with two valves in parallel and 50 volts on the plates, clear amplification is best obtained with a grid potential of −6 volts; if a leaky grid condenser is used to obtain negative grid potential, with 4 volts on the filament, the above amplifying point could not be attained. This is a point which requires attention when using two valves in parallel for reception; also on higher plate voltages the valves are very liable to inter-oscillate and set up yowling. For both reasons low plate volts should be used for reception. In connection with the 50-volt curve for the two valves in parallel the plate current valves when the valves were oscillating, and an aerial circuit connected, are shown by the dotted loop.

Best Points of Functioning.—Having considered the valve as a generator of oscillations we are in a better position to make further investigation into its behaviour on a receiver, using it as a detector, an amplifier, or a detector-amplifier of spark or C.W. signals.

A simple receiver circuit was made up similar to that of Fig. 72 and strength of signals noted at different points of the curves. Fig. 77 shows actual characteristic curves of a French valve (S type) with 4 volts applied to the filament and different potentials

on the plate; these values are marked on the respective curves. The point on the curves at which the valve rectifies like a crystal detector without reaction coupling are marked R. For instance. with 15 volts on the plate 6 volts negative are required on the grid for this rectification, with 75 volts on the plate it is best to have —12 volts on the grid. (If the heating of the filament is reduced by reducing the filament volts the curves will all move towards the right, thus less negative potential will be required on the grid to give the valve these rectifying properties.) As might be anticipated it will be seen that these points are all at the termination of the flat parts of the respective curves, and since the curves do not rise steeply from these points, except on the high plate potentials, it is only on high plate potential and comparatively large negative grid potential that the valve will give results, as a detector, approaching those obtained with a good crystal.

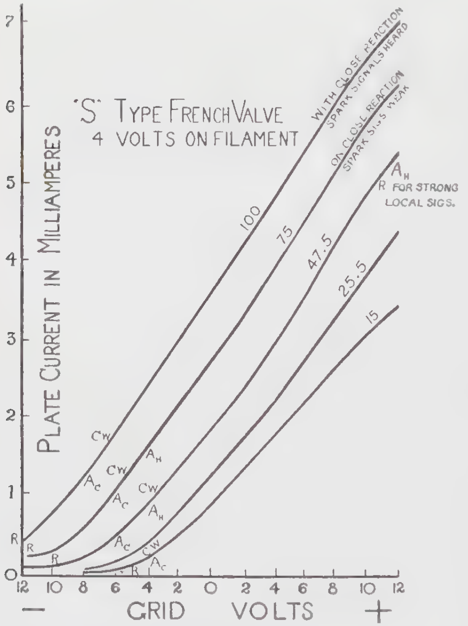


Fig. 77.

It has been already explained that if a very small leaky condenser is connected in series with the grid, instead of a voltage regulating potentiometer or battery, the valve will have better rectifying properties than at any of the points considered above, owing to the increase of negative grid potential when a train of waves from spark transmission arrives.

It only remains to say that when using a grid condenser the rectification will apparently be better for higher plate voltages, depending as it does on the slope of the plate current curve at the point corresponding to —4 volts grid potential. It will be found, however, that a plate potential of 75 volts will give results which are not augmented by a further increase of plate voltage, the

slope of the curves at this point not increasing to any extent for higher voltages.

To obtain amplification of the received oscillations the reaction coil in the plate circuit is coupled back to the receiver or grid circuit, so that the potential oscillations of the latter are increased. With the reaction coupling kept close, and fixed, the points at which the *clear note* of the received signals was best amplified are shown at A_c in Fig. 77. At these points with no reaction coupling no signals were received: with close reaction coupling the signals were strong and clear. The fact that the signals were strong and clear shows that oscillations set up in the plate circuit current by the received signals were reinforcing the received oscillations by means of the reaction coil, that the resultant oscillations were being rectified, and that the valve circuits of themselves were not generating oscillations because there was no impulse of energy in the grid circuit.

Under these conditions we see that, for clear amplification with a fixed reaction coupling, the higher the plate potential the greater must be the negative potential of the grid, and that the amplifying points are higher up the curves than the ordinary rectifying points.

With the same close reaction coupling the points marked A_H higher up the curves were obtained; at these points the signals were stronger but hoarse, so that the quality of the transmitter note was lost. The valve was now generating oscillations and heterodyning the received signals; when the reaction couplings was loosened the amplification became clear but signals were not so good as at a point lower down the curve. For example, consider the curve corresponding to 47·5 volts plate potential: with no reaction coupling and -8 volts on the grid the valve acts as a detector, with close reaction coupling and -6 volts on the grid it acts as a detector-amplifier. With -4 volts on the grid and the same reaction coupling it acts as a detector-amplifier and heterodynes the signals by its own generated oscillations. By loosening the coupling the valve oscillations will be stopped, and then with -4 volts on the grid it will give the clear note of the transmitting station; it will act as a detector-amplifier but will not be so good as at -6 volts grid potential, where the detector effects are better—being nearer the bend of the curve—and the amplifier effects no worse, since the slope of the curve is about the same. The use of a series grid condenser is dealt with later.

Suppose the grid potential is increased to, say, 2 or 0 volts;

we are then working the valve higher up the curve and may get amplification with a hoarse note, but the signals will be weaker, for we have gone too far away from the point where good rectification occurs. On ordinary signals amplification accompanied by heterodyne effect does not extend far up the curve because there must always be rectification for signals; ordinary signals give but a small swing of grid potential, so that the valve must be functioning near a rectifying point if the grid potential is to swing through it when signals arrive.

At points higher up the curve strong local signals may be received with reaction coupling: they may be clear because the valve has ceased to oscillate and is near its saturation point, therefore rectifying; they may be hoarse because the valve is feebly oscillating, therefore heterodyning and rectifying. This is shown on the curves of Fig. 77. When functioning at a point high up the curve the valve is not apparently adjusted for rectification and reception of signals, but strong local signals swing the grid potential with sufficient amplitude to make it pass through the value where rectification at plate current saturation occurs.

Now let us assume that, instead of varying the grid potential, we have a small leaky condenser in series with the grid—what will be the result as regards amplification and heterodyning? With 4 volts applied to the filament the grid will be 4 volts lower in potential than the highest potential point of the filament, if properly connected up as in Fig. 14. Referring to Fig. 77 it is seen that at -4 volts on the grid the valve amplifies with 15 volts plate potential and close reaction coupling; it will amplify better with 25·5 volts since the curve is steeper; it will amplify and heterodyne with 47·5 volts but with looser reaction coupling will give clear and still better amplification on this curve.

With still further increased plate voltage it is probable that no advantage will be gained, since with close reaction the valve will oscillate strongly, and with reaction loose enough to stop the oscillations but still give amplification the latter will be no better than that obtained by proper adjustment of reaction coupling on 50 volts plate potential.

For C.W. auto-heterodyne reception the valve *must* oscillate to form beats with the incoming oscillations, and the amplitude of the valve oscillations must not be too strong. Thus, when using a grid condenser, we can receive strong local C.W. signals with 15 volts, can get better results with 25 volts, and better still with 50 volts; with 75 or 100 volts we shall still receive the signals with

this arrangement for putting —4 volts on the grid, but the signals would be improved by having —5 to —6 volts on it.

Effect of Changing the Filament Temperature.—Fig. 78 shows the effect of regulating the filament temperature of a French valve, keeping the plate volts, reaction coupling, and aerial capacity constant. It is seen that clear amplification is obtained at —4 volts grid potential with 3·5 volts on the filament, but the valve oscillates and heterodynes the signals at the same grid potential

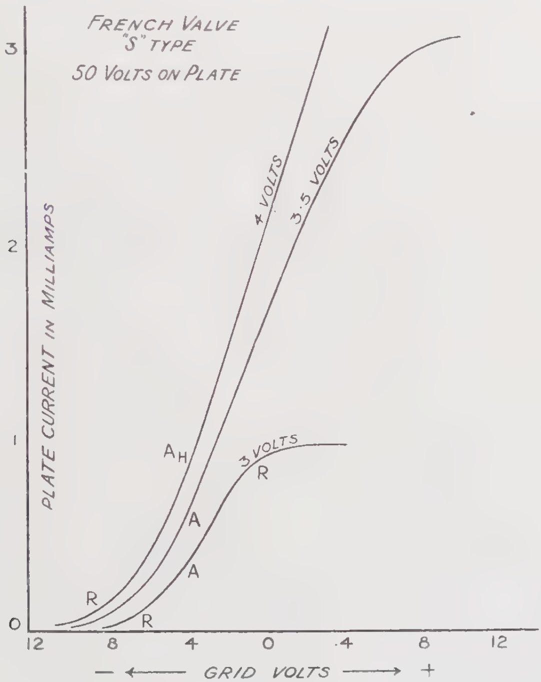


FIG. 78.

with 4 volts on the filament. It is evident, therefore, that adjustment for good signals can be made on the filament temperature by means of a series rheostat, keeping plate potential constant and grid potential at a point not above that of any portion of the filament. This can be provided by means of a leaky condenser in series with the grid, and the curves show us that good signals will be obtained with 3 volts on the filament and 50 volts on the plate. If the filament potential is adjusted to a valve between 3 and 4

volts best signals will be obtained with a plate potential of from 20 to 30 volts.

Harmonics.—When the fundamental oscillations in a circuit are accompanied by other subsidiary oscillations the latter are called *harmonics*. The second harmonic is an oscillation of double the frequency of the fundamental, the third one of treble the frequency, and so on. When the harmonic oscillations are of lower frequency than the fundamental they are called *sub-harmonics*.

Fig. 79 (*a*) shows the form of an oscillating current consisting of a sine wave fundamental and a small second harmonic, the fundamental and the harmonic being shown dotted. Similarly a fundamental and a third harmonic are shown at (*b*) and a fundamental and seventh harmonic at (*c*).

In wireless transmitting circuits it is important not to have much energy oscillating on harmonics, since it is wasted as far as the distant receiver is concerned, and it may interfere with neighbouring stations working on the frequency of the harmonic.

In spark telegraphy, where the transmitting aerial circuit is sharply tuned and loosely coupled to the oscillating circuit, not much radiation occurs on harmonics except from high-power stations. In C.W. working where the aerial may be, as it often is, directly coupled to the valve oscillating circuit some harmonics and sub-harmonics can generally be detected.

For example, C.W. messages from a long wave station have often been read on a valve receiver of short wave range, or on short wave setting. This may be because the transmitting station is radiating some energy on a high frequency, short wave, harmonic, or because the valve receiver, oscillating on a short wave fundamental, is also weakly oscillating on a long wave sub-harmonic which forms beats with the received oscillations. Oscillograms have shown that the Poulsen Arc Generator is rich in the higher harmonics, and experience shows that signals from a Goldschmidt Machine can be picked up on its harmonics.

The oscillations of a valve are generally accompanied by harmonics and sub-harmonics, some of which can be noted on a wide range valve wavemeter held near the oscillating circuit. If the circuit and the valve wavemeter have oscillation frequencies and ranges as usually employed in wireless work not more than two or three harmonics can be detected within the range. Thus if the fundamental corresponds to a wave length of 1200 metres the second harmonics will be read at 600 metres and the third at 400 metres. A method of demonstrating harmonics is shown in Fig. 80

where two valve oscillating circuits are coupled together. By tuning them to slightly different frequencies a fundamental beat is

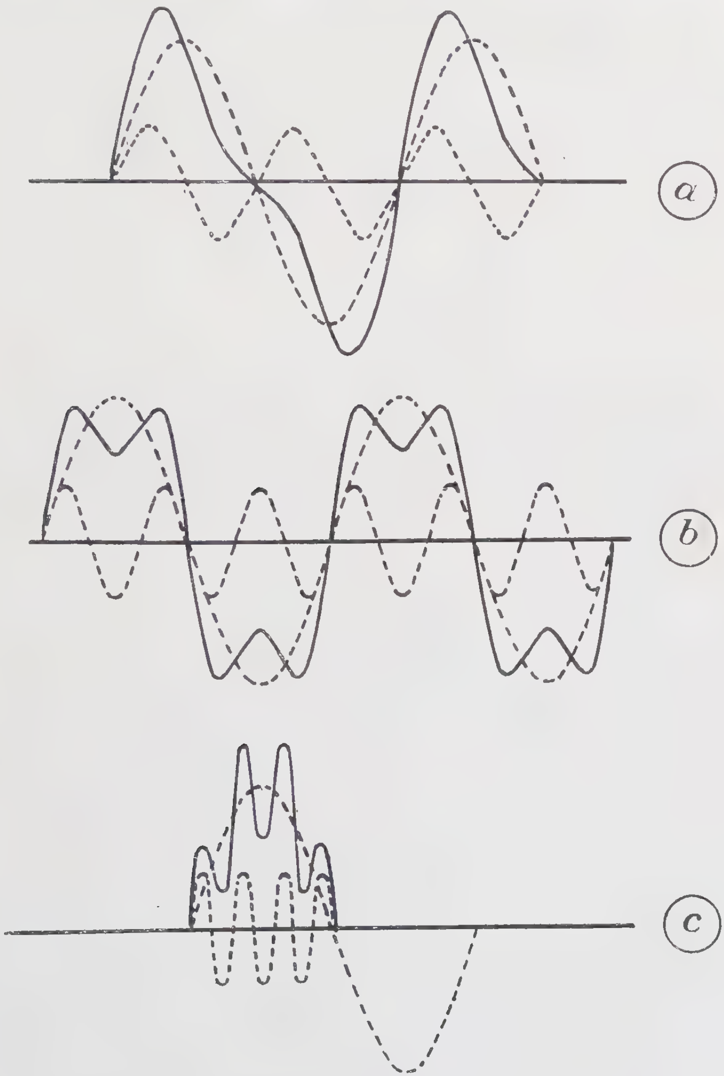


Fig. 79.

formed and the heterodyne note is heard in the telephones. If the two circuits are designed for ordinary high frequencies and tuned

by variable condensers of usual range, say 0 to ·002 mfd., the range on either condenser in which the heterodyne note is heard will be very small, and harmonics which might set up beats in the circuits cannot be detected within this small range. If, however, the two valves are tuned to oscillate at very low, though still inaudible, frequencies the fundamental beat note may be heard over the whole range of either condenser. By varying one condenser it is possible to hear very clearly, under the fundamental

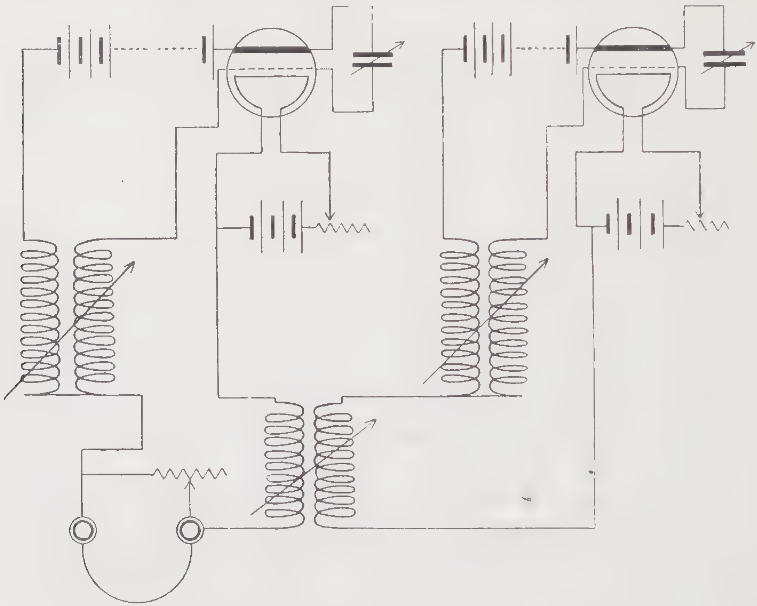


Fig. 80.

beat note, each harmonic of one circuit coming into beat action with the same harmonic of the other circuit. Fig. 80 shows the connections for this experiment; the tuning condensers give best results when connected from plate to grid of each valve, as a greater range of frequency is thus obtained within the compass of the condenser. As many as 6 or 7 harmonics may be detected in this manner.

Harmonics in a valve oscillating system may also be detected by placing a valve wavemeter near it; the wavemeter should have inductive tappings, or replaceable coils for different wave length

ranges, with a variable condenser of small maximum capacity across the grid or plate circuit. This will ensure a small wave length range for the full scale of the condenser; by using the different inductances we can then search over a wide range of wave lengths with a broad, open scale, and thus detect harmonic beats without much trouble.

The Multivibrateur.—An interesting method of making up a valve circuit which will provide oscillations rich in harmonics has been described by Professor Abraham of the Sorbonne, Paris; it is shown diagrammatically in Fig. 81 and is known as the Multivibrateur.

The resistances R_1 and R_2 in the grid circuits are of 75,000 ohms

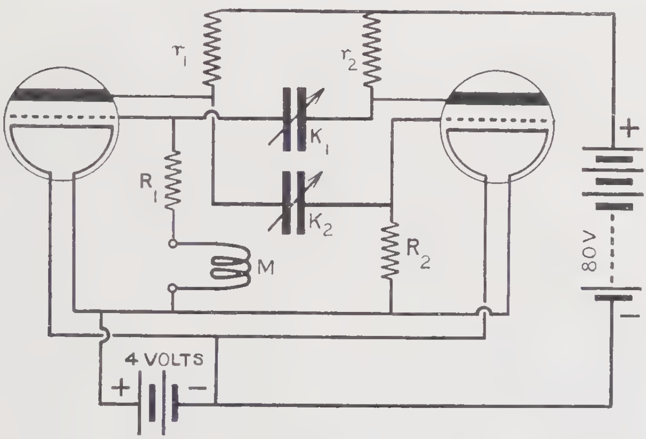


FIG. 81.

each, those in the plate circuit r_1 and r_2 being 50,000 ohms. Each of the variable condensers interconnecting the plate of one valve with the grid of the other has a maximum value of 0·01 mfd. These values will give oscillations which have a fundamental frequency as low as 1000 when the full value of the condensers is used. The fundamental frequency will be higher the lower the values of the condensers and resistances; it is possible, by using large capacities and resistances, to produce fundamental oscillations of so low a frequency that they can be easily counted on a milliammeter inserted in one of the circuits. Otherwise the oscillation frequency is noted by coupling the coil M in Fig. 81 to a heterodyne arrangement and comparing it with a known standard.

To explain the action, suppose a small increase of current to start in the first plate circuit, this reduces the plate potential since it increases the drop of volts in r_1; the potential of K_2 is also decreased and the condenser discharges. This decreases the potential of the second grid, and therefore decreases the second plate current with consequent increase of the second plate potential. Therefore the potential of K_1 rises, and it charges up, drawing current through the resistance r_1 from the battery; this extra current involves further reduction of the first plate's potential.

In this manner, by a process of building up, one grid becomes strongly negative and the other strongly positive: one plate current decreases to zero the other increases to saturation. This dissymmetry cannot be maintained and the reverse action soon occurs.

Thus current interoscillates between the valves; if the condenser and resistance values are large the rate of oscillation will be slow, and by suitable choice of values it is possible to obtain a frequency of one a minute, or of a musical note, or one too high to be audible. The fundamental oscillation of this circuit is accompanied by a great number of harmonics, of which even the 150th has been recorded.

It therefore provides an important method of calibrating wavemeters, since the fundamental oscillation can be made of musical frequency and can be measured accurately by comparison with a standard electrically controlled tuning fork. The frequency of the harmonics is thus known with great accuracy. If the frequency of the highest harmonic is not sufficiently great a second multivibrateur can be made, whose fundamental note may be adjusted to synchronism with one of the higher harmonics of the first one; its harmonics will then be raised in proportion, so that it is possible to calibrate down to comparatively short wave lengths by this method.

One method of calibrating a wavemeter with a multivibrateur is shown in Fig. 82; the small coil M of Fig. 81 is coupled to the circuit of the wavemeter, whilst a H.F. Amplifier-detector is coupled to the wavemeter and to a valve heterodyning circuit as shown. The fundamental oscillation of the multivibrateur is first determined as explained above, and a wavemeter roughly set to a reading corresponding to the frequency of one of its harmonics. The heterodyne circuit is then turned in to the wavemeter, and by varying the adjustments slightly a setting of the wavemeter will be found in tune with the multivibrateur harmonic, and with which the heterodyne circuit forms a beat note of loudest intensity in

the amplifier telephones. Care must be taken that the amplifier itself is not oscillating, also that there is no direct coupling between it or the heterodyning circuit and that of the multivibrateur. It is to be noted that the valve heterodyning circuit produces harmonics itself, and if, without changing the tuning of the heterodyne, the wavemeter tuning is set to half the wave length or

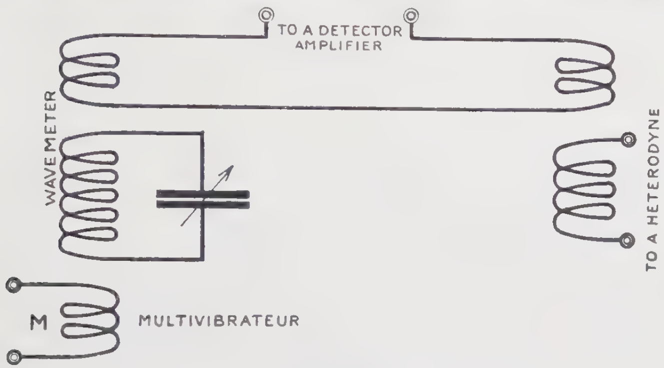


FIG. 82.

double the frequency, *i.e.* in tune with the next octave harmonic of the multivibrateur, it will form a beat with the second harmonic of the heterodyne.

It is seen that this serves as a very accurate method of verifying the calibration of a wavemeter since, in effect, it compares the whole scale with a standard tuning fork.

QUESTIONS ON CHAPTER IX.

1. How can an estimate of the saturation value of plate current be obtained without forcing the valve up to this value ?
2. A valve receiver on a fairly large aerial is not heterodyning spark signals nor receiving C.W. signals, even with close reaction coupling. Explain this, and say what adjustments you would make to try and receive C.W. signals under these conditions.
3. Under what conditions would it be better to use a potentiometer or grid cells rather than a leaky grid condenser with a French valve ?
4. Discuss the advantages and disadvantages of using two valves in parallel for detector purposes.
5. Explain how a valve detector may be adjusted to a sensitive point by simply having an adjustable rheostat in series with its filament.
6. For the reception of spark signals by means of a French valve receiver, fitted with reaction coupling, why is it that 100 volts plate potential does not generally give stronger signals than 50 volts ?
7. What are harmonics ? If the fundamental wave length of a circuit is 1000 metres what is the frequency of its third harmonic ?

CHAPTER X

DESIGN AND CHARACTERISTICS OF VARIOUS RECEIVER VALVES

Before the outbreak of the war the only hard vacuum valve which had come into prominence was the Pliotron, produced in

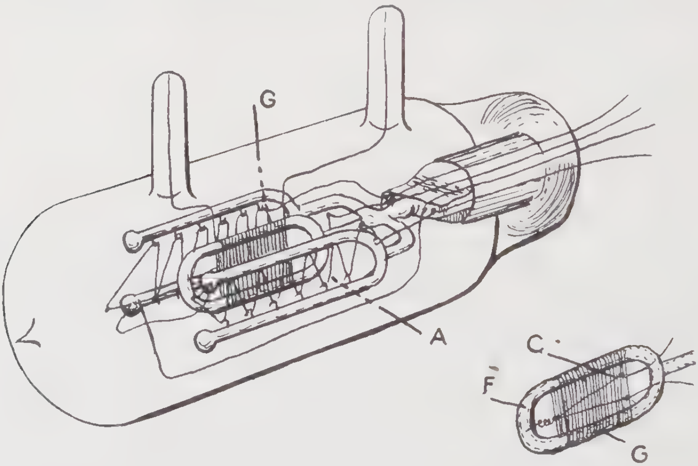


Fig. 83.

the United States by Dr. Irving Langmuir, under the auspices of The General Electric Co. of America; the date of his application for patent being 16th Oct. 1913. This valve, its characteristics, and its applications were described by Langmuir in a paper read by him before the Institute of Radio Engineers, April 5, 1915; it was made in large sizes for generating oscillations and in small sizes for use on receiver apparatus.

The construction of one of the original small Pliotrons is shown in Fig. 83; it is seen that the filament, C, is of hairpin shape, the top being held by a spring shock absorber to the glass framework, F, supporting the grid. The grid, G, was of fine tungsten

wire wound on a glass frame around the filament, while the plate, or anode A consisted also of fine wire supported on glass stems outside the grid.

It is apparent from the fineness of the grid mesh and its closeness to the filament that this valve should be very sensitive to slight changes of grid potential ; a small negative grid potential should stop the plate current altogether, whilst a small positive potential should greatly increase the plate current. In other words the valve should have a steep characteristic curve of plate current with a well-defined rectifying bend.

On March 3, 1915, Edwin H. Armstrong read an interesting paper on Hard Vacuum Valve Characteristics and Circuits before the Institute of Radio Engineers. It was the first exhaustive exposition of valve action in which the effects of rectification, high and low frequency amplification, oscillation generation, and cascade effects were fully accounted for, by arguments which hold good even in the light of subsequent development and more widespread experience.

In connection with this paper Armstrong exhibited two oscillograms taken at Columbia University, the first demonstrated the effect of grid potential changes on the plate current when working on the steep part of the curve ; the second showed how, with a series grid condenser, the grid potential falls during rectification and causes pulses in the plate current. These oscillograms are reproduced in Figs. 84 and 85 by permission of the Institute of Radio Engineers.

In 1915 the Pliotron valve had not come into general use in Europe, but about this time the French type of Pliotron valve made its appearance, and its use in the Western Allied armies became general in 1916. Since the introduction of the French valve many copies of it have been designed by British manufacturers, and later in the war by German manufacturers, after samples had been captured. Many of these were decidedly inferior to the French, failing either in uniformity of action, in shape of characteristic, or in economy of energy. Some have, however, proved superior for definite purposes ; for example, one valve may be efficient as a rectifier but may prove to be poor as a generator of oscillations ; another may have a characteristic which makes it suitable for use in L.F. Amplifiers, because it is free from oscillations set up by parasite effects. These points will become clear in the following descriptions of various valves and their characteristics.

Before individual valves are dealt with a few general remarks

on energy efficiency, cost, and design may not be out of place. The energy taken by a valve includes that required to heat the

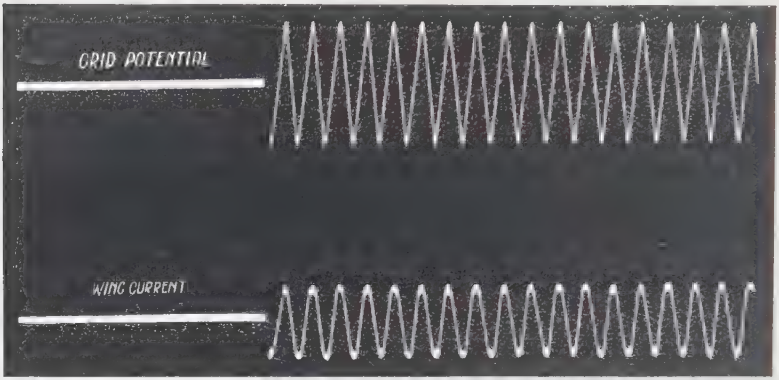


FIG. 84.

filament and that taken from the plate circuit battery even when no signals are coming in. The Round soft vacuum valve, which is one of the best of its kind, takes only a fraction of a milliampere

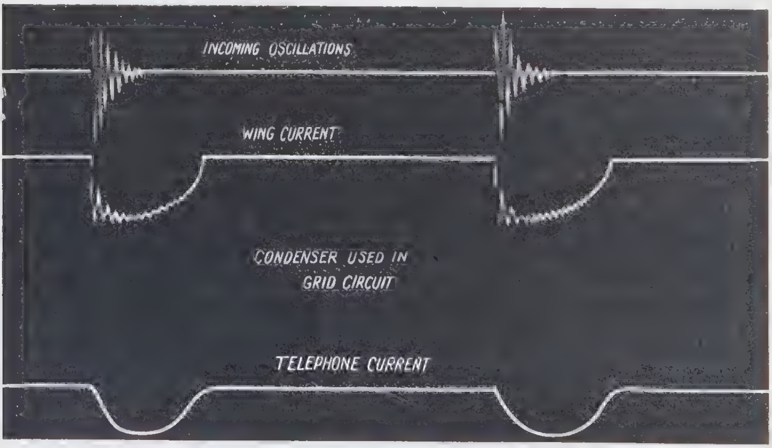


FIG. 85.

from the plate battery when suitably adjusted for reception purposes, and in the present form is remarkably constant in action

on 50 volts. It requires 2 volts on the filament and takes 3 amperes of filament current. Hence its total consumption of energy is about 7 to 10 watts, allowing for the necessary rheostatic control of the filament temperature and potentiometer control of the grid potential.

The French valve takes about 0·7 ampere of filament current with 4 volts applied, and about 1·5 milliamperes at 50 volts from the plate battery: its energy consumption is therefore about 2·9 to 3 watts. But it is possible that the supply and life of the plate batteries may be a more serious consideration than energy efficiency: it has in fact influenced the design of many valves. The valves made by German manufacturers in the early part of the war functioned with very small current in the plate circuit, a great advantage in view of the difficulty of keeping up renewals of plate batteries to Front Line apparatus.

As regards cost the hard vacuum valve was much cheaper than the soft vacuum ones which it replaced; this was natural because it marked progress rather than innovation as far as cost is concerned.

As regards general assembly and workmanship the excellent construction of the German-made valves, especially in the glass-work, is always noticeable.

The characteristics of the French valve have been dealt with in the preceding chapters: those of some other valve designs will now be given, in order to bring out more fully the influence of design, not only on the sensitiveness of valves but also on their suitability for particular applications. The valves chosen for description will be dealt with more or less in the order in which they made their appearance.

In comparing valves some difficulty arises as to the basis on which the comparison shall be made. Some writers have compared valves on the basis of equal filament temperatures, these being adjusted by photometric methods. Such a basis is hardly a practical one and may be unfair: for example, a valve may be one of the most efficient for a particular purpose though its radiation of electrons may not bear a high ratio to the filament energy input or temperature. The same remark applies to comparisons made under the conditions of equal plate potentials.

It seems best, therefore, to compare valves on an ordinary standard receiver circuit, using conditions as regards filament temperature and electrode potentials such as are likely to be available or convenient in practice; if possible adjusting these to

the values for which the valves are guaranteed. Having found the efficiency of a valve for a practical purpose under these conditions the electrical efficiency can then be noted, though it will probably prove to be a secondary consideration.

Most of the comparisons which follow have been made on a standard receiver circuit, so that the behaviour of a valve as an amplifier of oscillations through reaction coupling, or as a generator of oscillations, may be noted at the same time as the ordinary characteristic curve of the plate current is obtained.

With some valves, such as the French type, oscillations will occur under certain conditions when coils are included in the plate and grid circuits even though they are not apparently coupled; this will lead to errors in plotting the non-oscillating characteristics unless the coils are left out, or care taken to neutralise any possible coupling effect.

N.P.L. Valve.—In this valve the plate was a thin sheet of circular metal; above this was the grid consisting of a perforated sheet of metal, beyond which was a bowed tungsten filament, the centre of the bow being close to the grid. This was a bad design; the grid was too heavy and the flow of electrons from the filament was not uniform along its length but was concentrated at the centre. The design is now out of date, but the valve is dealt with here, as it is a sample of a distinct type.

The characteristic curves of three of these valves are shown in Fig. 86: it will be noted that the valves are not uniform, the curve of No. 3 being entirely different from those of No. 1 and No. 2. Again it is seen that there is a decided kink in the curve of each valve, the kink occurring on that of No. 1 valve between 0 and +2 volts grid potential. This kink denotes the presence of a small amount of mercury vapour in the valve, and from its appearance there seemed to be a mercury amalgam on the plate which would account for the presence of this mercury vapour. The effect of a slight trace of gas or vapour in a valve was dwelt upon by Dr. Langmuir in 1915; he pointed out that there was an increase in the sensitiveness of such a valve if its grid potential was adjusted to make the valve function at the point on its curve where the kink occurs. Under these conditions either an increase or decrease of grid potential gives a decrease of plate current, so that the rectifying properties are efficient. The quantity of vapour necessary is very small, and comparatively high-plate voltages may be used without any indication of blue glow.

In the valve under consideration the conditions are not stable

at the lower end of the kink, and the plate current tends to jump up and down, as shown at XY, accompanied by noises which drown the signals. In valves 1 and 2 the plate current rose very suddenly when the grid volts were brought to more than +6, showing the effect of positive ionisation due to the gas in the tube.

When worked at 0 grid volts, which was the sensitive point for both these valves, spark and C.W. signals were good; on —2 grid volts with close reaction coupling signals were heard with slight

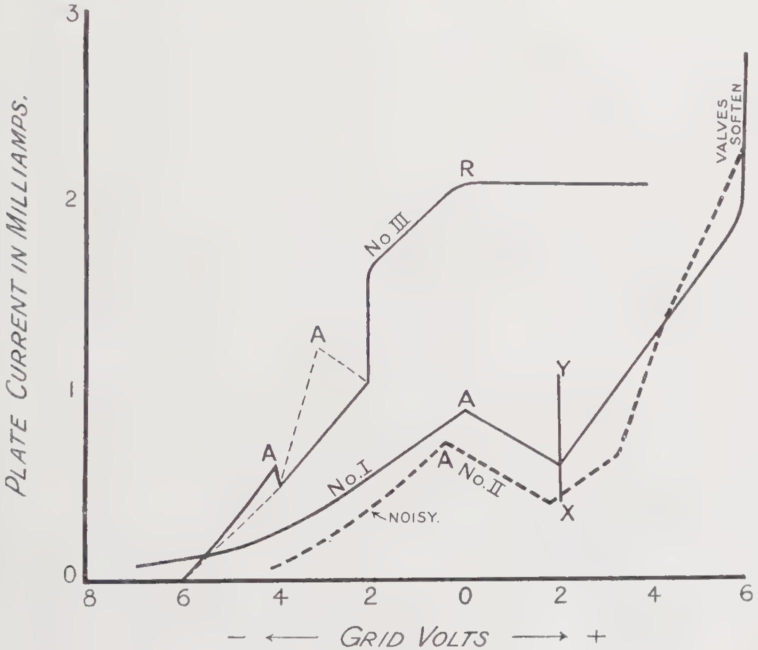


FIG. 86.

amplification and heterodyned, but the valves at this point were so noisy as to practically drown reception.

Rectification was noted on No. 3 valve at the point R as might be expected, also good amplification with reaction coupling at the points A, but the behaviour of this valve was very erratic. There are certain possible advantages to be gained by the use of a valve with a kink in its characteristic curve. If adjusted to function at the kink its amplifying effects is limited by the depth of the kink; it can be employed to strengthen up weak signals

to this limit and not strengthen strong jamming signals beyond this limit. A valve employed in this manner, or for the purpose of limiting jamming effects, may be called a "Limiter."

Fig. 87 shows the characteristic curves of two B.T.H. valves, Type A, of early manufacture, compared with that of a French S type valve. The curves were all taken with an aerial circuit connected and tuned to receive signals from local stations. In

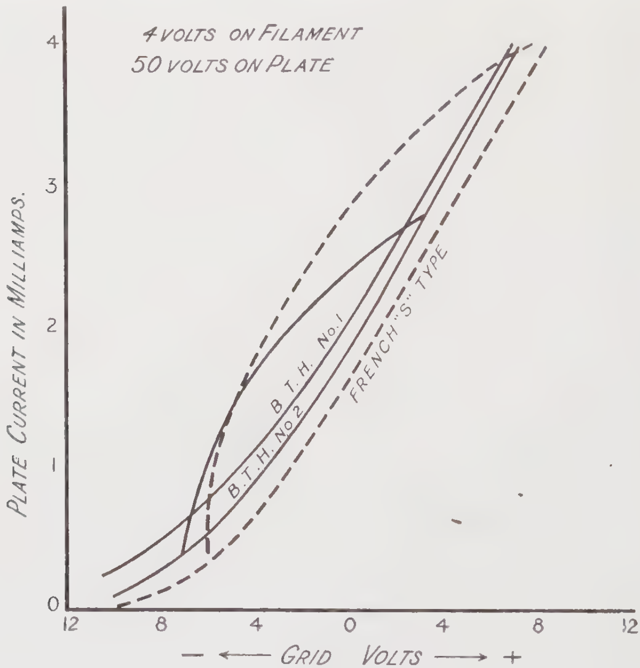


Fig. 87.

addition to the characteristic curves Fig. 87 shows the values of plate currents when the valves were oscillating with close reaction coupling. It would appear from these curves that the early B.T.H. valves were not uniform, took more plate current than the French valve, and had not as good oscillating properties. The saturation current of the French valve is higher than that of the B.T.H. valve as shown by the semi-curve under oscillating conditions.

C.W. signals were received best on the B.T.H. valves and on the French valve with —4 volts grid potential. Two other B.T.H.

valves, A type, were tested at the same time, and the results showed that the lack of uniformity in the current of the plate circuit for different valves was greater when the circuits were reacting and the valves oscillating.

The A type valve is identical with the French valve in general design, except that the spiral grid is stiffened by having a length of wire stretched across from one grid bracket arm to the other to which the spirals of the grid are fastened by an interlacing of very fine wire as illustrated in Fig. 88.

This stiffening of the grid reduced the microphonic noises which are so prevalent with the French valves, especially when used in Low Frequency Amplifiers.

The plate is a thin sheet of nickel 3·1 cms. long, 1·6 cms. broad, bent into a cylinder 1·6 cms. long and 1·05 cms. diameter. The grid has 11 spirals of 0·5 cm. diameter, the wire being about No. 35 S.W.G.; and 17 cms. long. All these dimensions are practically identical with those employed in the French valve.

FIG. 88.

The B.T.H. Company made a second type of valve, known as the B type, in which the design is similar to the A type, but the grid is of finer mesh, consisting of more spirals with a longer total length of wire; also the vacuum is probably harder.

The grid is a spiral of wire 0·5 cm. diameter with 23 or 24 convolutions and about 2 to 2·2 cms. long, the wire being (in the case examined) 2·36 cms. long and of about No. 35 S.W.G. Thus it has a closer grid mesh than the French or A type valves.

A straight piece of wire of the same gauge as that in the spirals is run along the entire length of the grid as shown in Fig. 88, the construction being similar to that of the A type previously described.

The curves of three of these valves are given in Fig. 89, with 50 volts on the plate and 4 volts applied to the filament. The filament current taken by this valve varies frgm 0·71 ampere to 0·74 ampere on 4 volts, as against 0·65 ampere for the French valve, and it will be seen from Fig. 89 that the oscillating characteristics are not uniform for different valves. It had a grid of fine mesh and its increased hardness of vacuum made it possible to apply a positive potential of 800 volts to the plate; this may be useful where the valve is employed for C.W. transmission, but it impairs the sensitivity and increases the damping effect of the valve when used on a receiver.

The closer and finer mesh of the grid in the B.T.H. B type valve partly explains why it does not require negative potential on the grid for reception purposes. In the curves shown in Fig. 89 it is seen that the valve functions best on a receiver circuit with positive grid potential when the plate potential is 50 volts and the filament current 0·725 ampere ; the plate current on fairly loose reaction will then be about 1 milliampere.

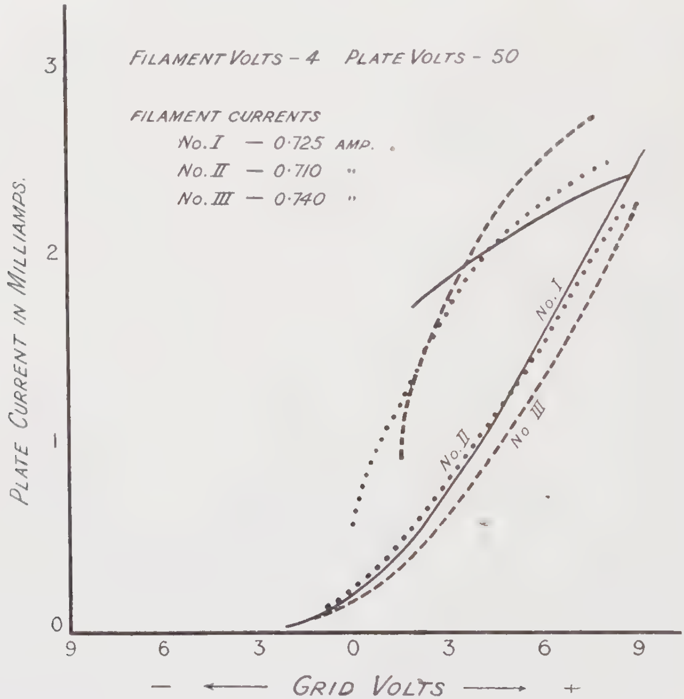


FIG. 89.

Fig. 90 shows comparative curves of a B.T.H. B type valve and a French S type valve ; it will be seen that with 50 volts plate potential and 4 volts on the filament the B type valve functions best as a detector with zero applied grid potential, whereas the French valve requires about —6 volts on the grid.

When 6 volts are applied to the filament of a B type valve the plate current curves moves over to the left ; its best working point

moves over into the region of negative grid potential, as in the case of French valves.

A small valve designed by H. J. Round and known as the Marconi Q type valve is shown full size in Fig. 91. It is 3 inches long and $\frac{9}{16}$ inch diameter with a straight tungsten filament through the centre, supported by stiff wires from the terminals.

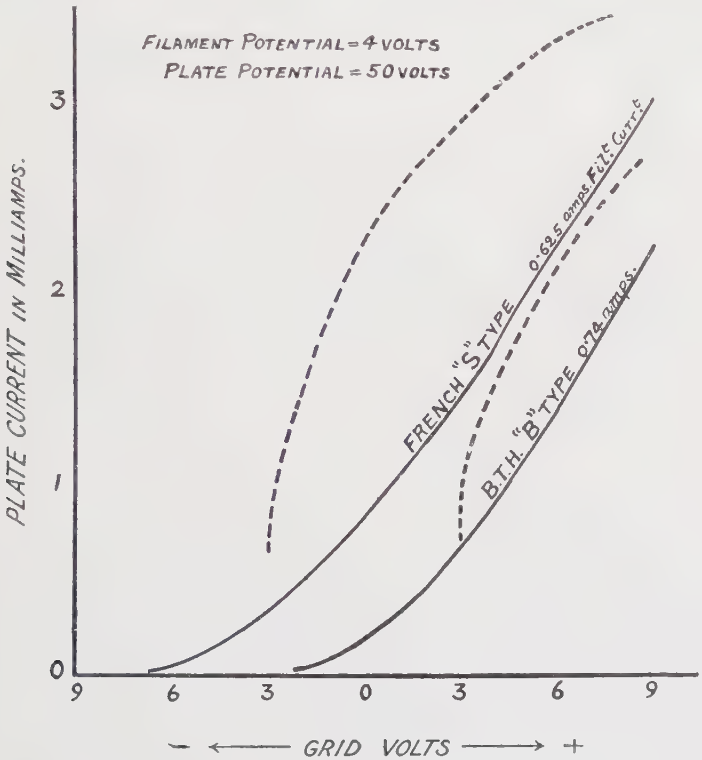


Fig. 90.

Connection is made between one lead-in wire and the filament by a small spiral wire, not shown in the Figure, which is intended to absorb mechanical shocks. The grid is a woven mesh of wire surrounding the filament and supported at each end by two glass beads carried on the filament lead-in wires; two stiff wires connect the beads and help to make the grid rigid. The plate is similar to that in the French valve, but it measures 2 cms. × 5

cms. when flattened out, and its distance from the filament and grid is greater, so that the effective plate circuit resistance has a relatively high value. The filament takes 0·29 to 0·33 ampere on 4 volts and the valve was at first designed for a plate potential of 150 to 200 volts ; this high voltage on the plate was somewhat of a disadvantage, but a considerable advantage was gained in the small filament currents on which the valve functions.

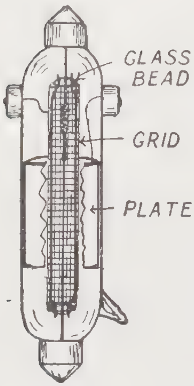


Fig. 91.

Its characteristic curves were very good ; they are shown in Fig. 92, in comparison with those of a French valve. In Fig. 92 the dotted lines show the points at which the Q valve oscillates with reaction coupling, when the aerial was connected and the signals were being received. The points at which rectification without amplification takes place are shown at R, while amplification points are shown at A. There is good rectifying action

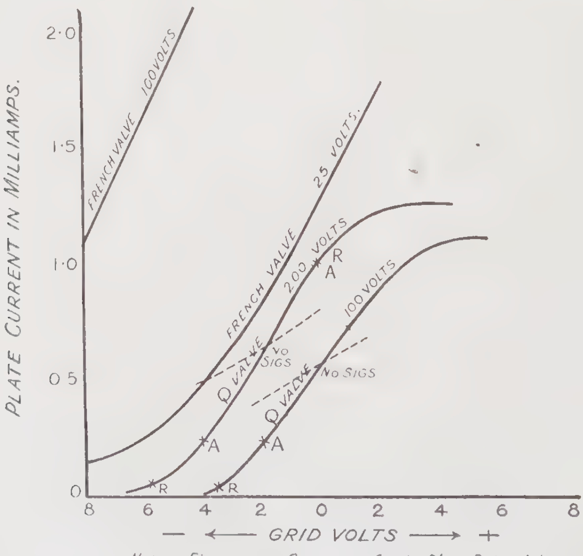


Fig. 92.

and no microphonic effect. The distance of the plate from the

grid and filament ensures good grid control and a good slope of characteristic.

Dealing with the 200-volt curve the valve acts as a detector with —6 volts on the grid; at this point also there was slight amplification with close reaction coupling. With —4 volts on the grid best signals were obtained with clear amplification when the reaction coupling was loose enough to prevent the valve oscillating. On closer reaction coupling the valve generated oscillations and this adjustment gave the usual heterodyned signals. This shows that the valve will function well with a small leaky condenser in series with the grid and 4 volts on the filament.

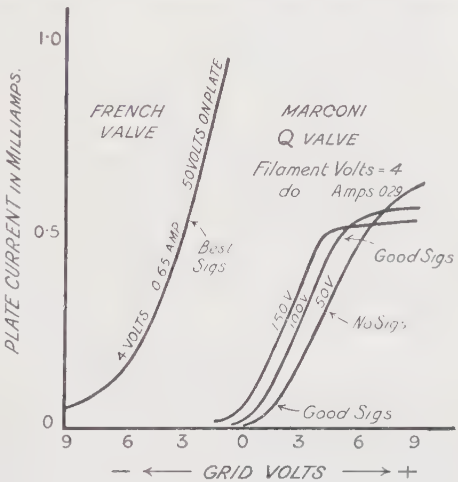


FIG. 93.

At —2 volts on the grid no signals were obtained, and on examining the curve it is seen that the valve oscillates here without rectification.

At 0 grid volts there was a faint detector action on strong signals without reaction coupling; with reaction coupling there was good clear amplification when the coupling was loose, but heterodyning when the coupling was made close or the aerial series condenser brought to a small value. Either of the latter adjustments start generation of partially rectified oscillations in the valve, hence heterodyned signals result, as they would in any hard vacuum valve working near the saturation bend.

With 100 volts plate potential best signals were obtained with —2 volts on the grid, the amplification being hoarse or clear according to the value of the reaction coupling and aerial capacity. At zero grid potential no signals were obtained, but amplification was noted at +2 and —4 volts grid potential, also detector action without reaction coupling at the latter point on the curve.

Fig. 93 shows the curves of a later modification of the valve which functions well on 150 volts plate potential. It will be noted that this later design requires positive potential on the grid;

owing to the steepness and shortness of the characteristic curve the grid potential is best obtained by a potentiometer adjustment. Curves obtained with a still later design are shown in Fig. 108.

A valve made by the A.E.G. Company is shown in Fig. 94. The characteristic curve of this valve, as compared with the French one, is shown in Fig. 95; it is seen to be very flat, partly due to the coarseness of the grid mesh, but also partly due to the smallness of the filament from which there was not much radiation of

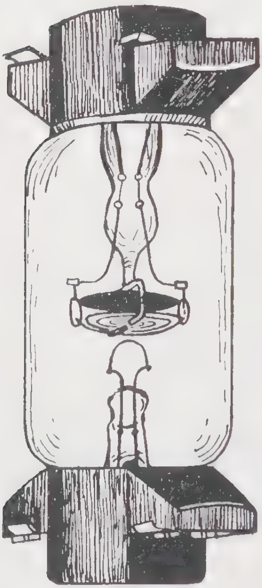


Fig. 94.

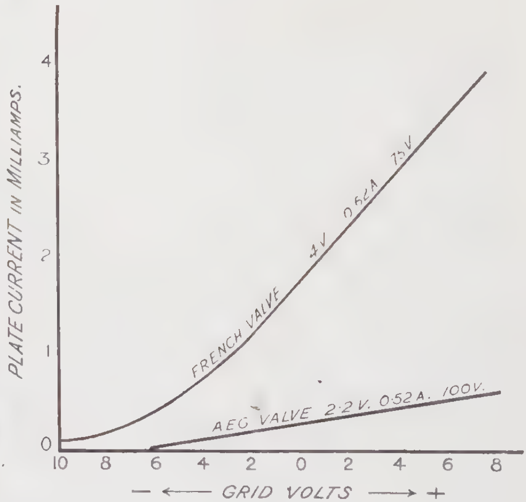


Fig. 95.

electrons, and partly due to the one-sided arrangement of the electrodes.

On 200 volts plate potential the plate current is at saturation at all grid potentials from -9 to $+9$. The valve is not nearly as sensitive as the French one for relaying or amplifying low frequency pulses; it does not oscillate, therefore will not amplify high frequency oscillations to any extent, nor act as a heterodyne. At the time this valve was in use there was no evidence to show that the Germans used valves on high frequency work, and apparently they employed them only for low frequency amplification.

The filament current of this A.E.G. valve must not exceed 0·52

ampere, and the advantages which the valve possessed were: first, it took a very small current from the H.T. battery so that the latter could be small and light; second, it was very steady when used in L.F. Amplifiers with an entire absence of noise, microphonic or otherwise. The valve is badly designed, the grid is too coarse and the filament too small; also the distance of the filament from the grid and plate is not uniform.

A second and later type of valve made by the A.E.G. Company

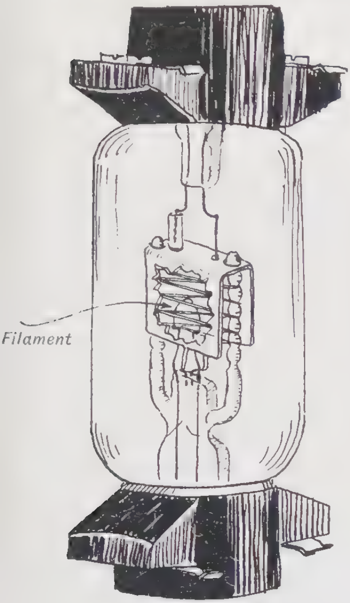


FIG. 96.

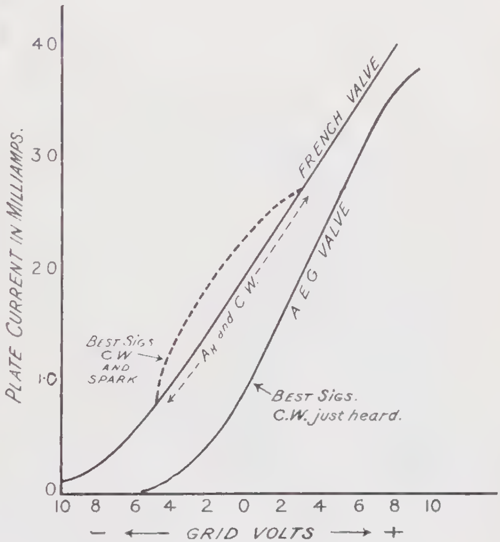


FIG. 97.

is shown in Fig. 96, while its curve compared with that of a French valve is shown in Fig. 97.

This valve resembles closely the original design of Audion. The valve was guaranteed for use with a filament current of 0·56 ampere, but the resulting curve on this filament current is very poor and flat. The curve shown in Fig. 97 was obtained by pushing up the filament current to 0·6 ampere with an applied E.M.F. of 3 volts, and with 75 volts plate potential.

Good amplification of signals was then obtained with zero applied grid potential and close reaction coupling, the plate current being about 1·1 milliampere. The signals were heterodyned, and

C.W. signals heard faintly, so that the valve must have been oscillating, but its oscillating component of plate circuit current was so slight that it could not be detected on the milliammeter.

With the French valve, using 0·52 ampere of filament current on 3·72 applied volts and +75 volts plate potential, C.W. and spark signals had more than twice the strength of those in the German valve. The French valve had −4·5 volts applied to the grid and the plate current was about 0·9 milliampere.

Fig. 98 shows the construction of a valve made by the Telefunken Company, of which two were captured with a Low Frequency Amplifier in the German lines during the operations in March, 1917. The plate, grid, and filament were very firmly supported on glass brackets and tying pieces so that there was no relative movement, and as a consequence, when the valves are used in an amplifier, there is an absence of microphonic noises in the telephones on shaking or jarring the apparatus. The characteristic curves of these valves are shown in Fig. 99; compared with those of the French valve they are very poor. The curve of the Telefunken valve had not a steep slope, therefore it did not amplify nor relay to the same extent as the French valve; this flatness of slope in the curve is partly due to the very open mesh of the valve grid and is also due to the fact that the plate and grid do not surround the filament.

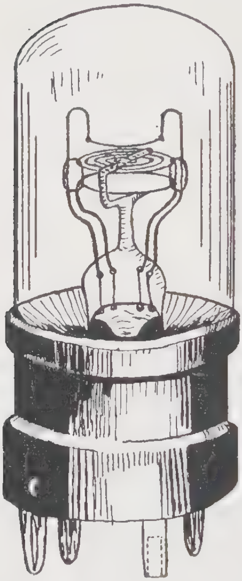


Fig. 98.

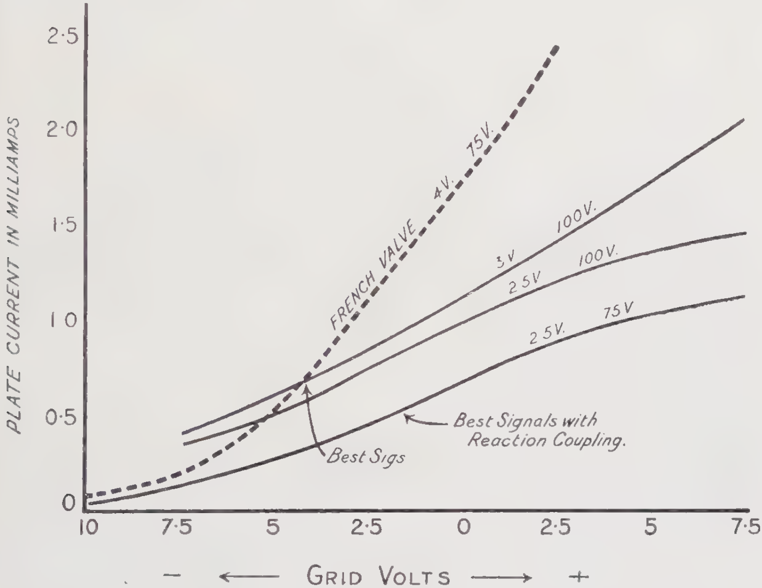
It will be noted that there is no sharp bend in the characteristic curve, so that this valve had not good rectifying properties and was poor as a detector. However with reaction coupling between the plate and grid circuits the valve amplified and gave best signals with about −1·5 volts on the grid.

The valve was a poor oscillator, and no difference of plate current was noted when the reaction coupling was made close, nor were the signals heterodyned. It was essentially a valve with a uniform, though not steep, characteristic, for use in Low Frequency Amplifiers. The fact that it did not easily generate oscillations made it work very silently in L.F. Amplifiers.

The best filament voltage is about 2·6 volts, and the plate

potential then required is from 75 to 100 volts ; when used in an Amplifier it appeared to function best on 50 volts, though in the German apparatus a 90-volt battery without tappings was supplied.

This valve was very sensitive to change of filament voltage, an increase of the latter starting yowling or hissing in the valve, while a decrease cuts out the signals. In the 2-valve L.F. Amplifier with which these valves are used there is a baretter of iron wire enclosed in hydrogen in series with each filament ; this



Note Figures on Curves show corresponding Filament and Plate Voltages.

FIG. 99.

serves to keep the filament current constant on slight variation of battery voltage. The amplifier also contains an extra filament rheostat coil wound on a bobbin. A 6-volt Edison battery was used for providing the filament currents of the two valves. This type of valve was used in the Amplifier of Fig. 54. A later design of the same type is shown in Fig. 100 ; it had a shorter filament and was evidently designed to be used under the same conditions as the A.E.G. valve, No. 8081, shown in Fig. 94.

The Marconi Company have constructed a valve known as the V. 24 which, in design, follows closely the lines of the French

valve but in shape is similar to the Q valve. The arrangement of plate, grid, and filament is similar to that in the French valve, but the plate and grid diameters are smaller and therefore these electrodes are closer to the filament. Like the Q valve the filament circuit inside the valve includes a small spiral spring to absorb mechanical shock, also the plate and grid leads are brought directly out through the sides of the glass tube, thus ensuring that the capacity effects in the valve are a minimum.

Its characteristic curve with 4 volts across the filament and

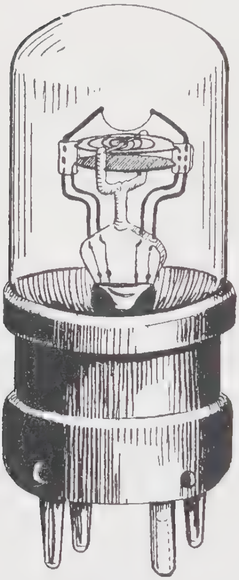


Fig. 100.

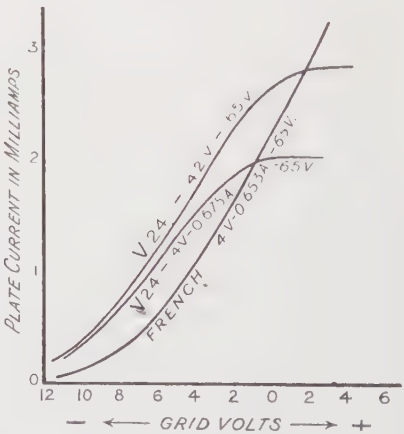


Fig. 101.

65 volts plate potential is shown in Fig. 101, together with the curve of a French valve under the same conditions. The filament and plate potentials are marked on the curves.

It is seen that this valve is suitable for use in H.F. and L.F. Amplifiers, having the advantage of functioning on small plate current ; it is not suitable for rectifying or heterodyning, though it does give rectification at the saturation bend and slight amplification when the plate circuit reacts on that of the grid ; it also oscillates slightly just below the saturation bend. Its saturation current is not increased by increasing the plate potential. The

valve requires negative potential on the grid and is not suitable for use as a detector with a leaky grid condenser. One advantage of its low saturation current is that the valve will have limiting properties which are useful for reducing jamming effects, as will be described in the next Chapter.

Late in the war, and after the Germans had captured samples of the French valve, they devoted their energies to the reproduction of a similar valve with the same characteristics; a delicate compliment to the scientific success of our Allies. The first German valve of French design which the author tested was dated 17–9–1917; it was made by the Telefunken Coy. and known as type E.V.E. 173; the design is shown in Fig, 102. The

TELEFUNKEN DRP.
TYPE E.V.E. 173

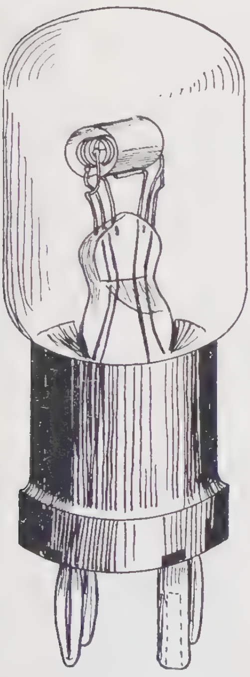


Fig. 102.

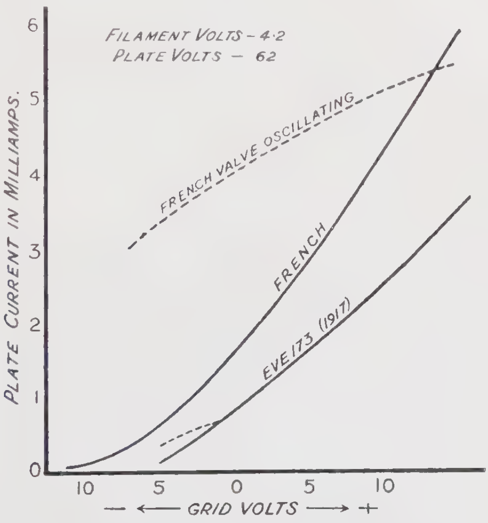


Fig. 103.

dimensions of grid, plate, and filament are very similar to those of the French valve; the plate is of nickel sheet but is only about three-quarters the diameter of the French valve plate. The grid is of thin nickel ribbon rather than wire, and has a stiffening rib along its length; the filament took 0·62 ampere at 4 volts as against 0·65 ampere taken by the French valve.

Fig. 103 shows the plate current characteristic of this valve

as compared with a French one, using 62 volts plate potential: it will be noted that the curve is farther over in the region of positive grid potential and has not so steep a slope as that of the French valve. This is due to the slightly coarser grid and to the smaller filament than that in a French valve. With 1·2 milliamps. of plate current the apparent plate resistance of the valve is about 50,000 ohms as compared with 24,000 ohms for the French Metal type valve.

For L.F. amplification with zero grid potential the German valve takes less plate current than the French one, but its amplifying power, as shown by the slope of the curve, is not quite so good. The valve was a poor oscillator when the plate and grid circuits were coupled, and required tight reaction coupling to receive C.W. signals at grid potentials between —2·5 and —4·4 volts. This is shown by the dotted curve. The oscillating current of the French valve under the same conditions is shown dotted; it can easily be realised that the French valve oscillates with much looser coupling and gives stronger C.W. signals.

For the reception of spark signals the German valve has a good rectifying bend; it gives good clear signals when used as a detector at the bend of the curve, and good amplification without much heterodyning effect when reaction coupling is employed. Its grid current is greater than that of a French valve, for positive grid potentials, but on working points for reception the grid resistances of both are equally high. In 1918 the Telefunken Company began to make these valves with copper plate and grid, probably owing to the scarcity of nickel. The copper showed signs of being chemically treated, possibly with cyanide of potassium and alcohol, to rid the surface of impurities and make the electrodes of different valves uniform in action.

Early in 1918 they produced a new valve, known as the R.E. 16 type, in which the arrangement of electrodes was still similar to that of the French valve, but the plate and grid were about half the diameter and therefore closer to the filament than in the E.V.E. 173 type. A French type valve was also made by Seddig of Nurnberg, with plate and grid of copper, but the plate and grid diameters were about the same as in the French valve, and larger than in the Telefunken E.V.E. 173. The plate current characteristics of all these valves compared to that of a French Metal type valve are shown in Fig. 104. The potential across the filament was kept constant in each case at 4 volts, and the plate potential at 65 volts.

The results of the comparison may be summarised as follows :—
The R.E. 16 valve takes a little less filament current than the French valve ; its plate circuit resistance is about the same and it gives the same plate current characteristic under non-oscillating

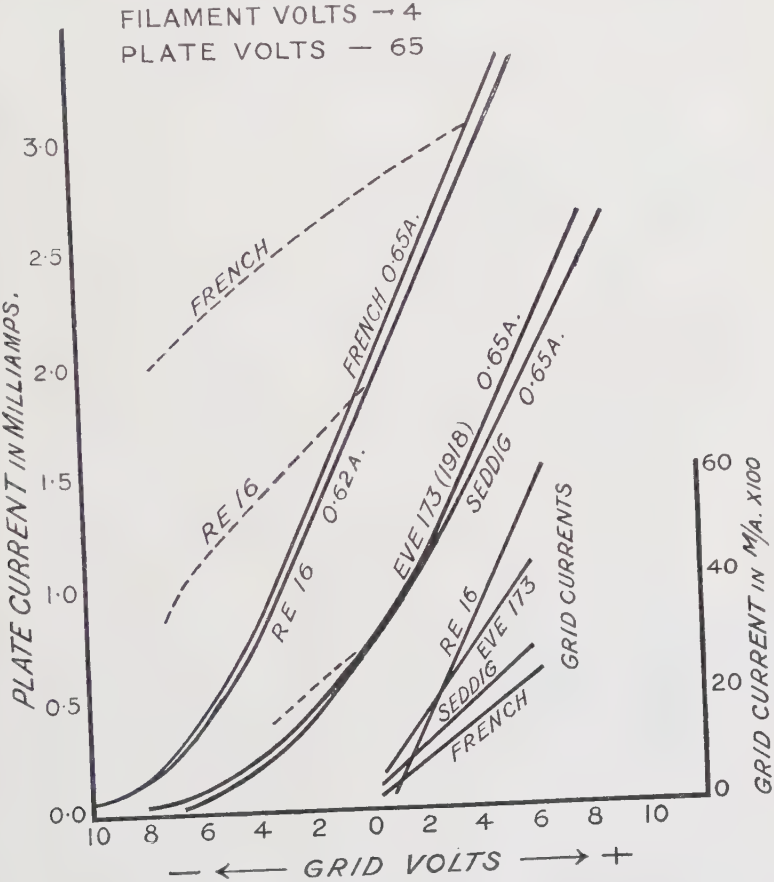


Fig. 104.

conditions. Its grid current is greater than that of a French valve, but equally small for working points as a detector ; it oscillates freely enough to make it suitable for heterodyning C.W. signals.

The E.V.E. 173 and Seddig valves take about the same filament current as the French valves, do not amplify as well, and

have a plate resistance about double that of the French valve for normal working plate current. They have good rectifying bends on the characteristics. The grid currents at reception values of plate current are small like that of the French valve. The valves do not oscillate freely even with tight coupling, both plate and grid currents reaching saturation earlier than those of the French valve.

The R.E. 16 type valve is interesting as its plate characteristic is practically identical with that of the French valve, though it takes less filament current and has the plate and grid much closer to the filament. With the plate potential and filament current noted, best reception of C.W. signals was obtained with 8·5 volts negative on the grid and a loose reaction coupling which made the plate current about 0·8 milliamp. We have seen that in

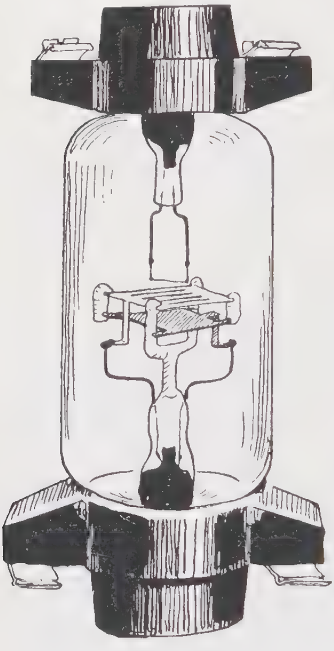


Fig. 105.

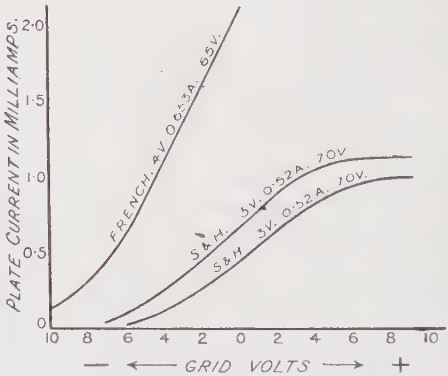


Fig. 106.

the Marconi V. 24 valve, where the plate and grid are closer to the filament than in the French valve, the characteristic is very different and reaches saturation sooner.

Valves were also made by the Siemens and Halske Company for use in low frequency amplifiers ; one of their designs is shown in Fig. 105. A second design was a slightly modified form of this one and gave a different characteristic. The plate current characteristics of these two valves compared with those of a French S type valve are shown in Fig, 106 ; the curves being marked

valve between the grid and the filament should be very high; it can be attained by having a fairly fine grid not too close to the filament. If the valve is required to generate oscillations, for C.W. transmission or heterodyne reception, the grid may be of coarser material or placed closer to the filament. The amplitude of valve-generated oscillations with loose coupling largely depends on the steepness of the plate current characteristic and a high saturation value. The greatest oscillation amplitudes will be obtained if the pulses of grid potential correspond to large pulses of plate current: these cannot be given if the saturation value is low, or if the plate current grid potential curve is not steep.

Dr. Irving Langmuir has shown that for a straight cylindrical filament inside a coaxial cylindrical plate of radius "r" cms. at a voltage V above the filament the maximum electron current per centimetre length of filament in a hard vacuum is given by:—

$$i = 14{\cdot}65 \times 10^{-6}\frac{V^{\frac{3}{2}}}{r}.$$

This assumes the filament to be at such a temperature that it emits a surplus of electrons. The importance of this equation lies in the fact that the proper hardness of vacuum obtained in a valve can be tested by seeing if the plate current plotted against plate volts follows the $\frac{3}{2}$ power law.

As regards the vacuum our ideas about a hard vacuum have been greatly changed since Langmuir obtained his results. Thus in 1906 Sir J. J. Thomson described an experiment where the pressure was reduced to about 0·001 mm. of mercury and later refers to this as a high vacuum; in his patents of 1904 and 1905 Dr. Fleming stated that for his valve a high vacuum must be made, and in his later patent of 1908 he explained that the bulb should have a good vacuum "such as is usually employed with lamps having metallic filaments," but elsewhere writes of the conductivity of this vacuus space or "ionised rarefied gas"; in 1909 Wehnelt described his difficulties in maintaining a vacuum of 0·1 micron (0·0001 mm.) of mercury in a bulb containing electrodes. Langmuir has shown us how very high vacua may be obtained in electrode carrying bulbs, so that for valves of receiver size, *i.e.* for use on low plate voltages, the vacuum now employed is at pressures of a few tenths of a micron (0·001 mm.), whilst for transmitting or high voltage valve the pressure should be of the order of one hundredth of a micron. According to Langmuir it is especially necessary to extract all traces of water vapour, oxygen

carbon monoxide, and hydrocarbon gases, as these will contaminate the surface of a tungsten filament and reduce its emissive properties, whilst the presence of a trace of argon may have the effect of cleaning the filament.

The electron emission from any filament will depend upon its material and may very largely depend on the condition of its surface as regards impurities, or deposits which may have condensed on it during or after the process of evacuation. Langmuir has shown that in the general case the average initial velocity with which electrons leave the filament is about sufficient to move them against a negative potential of 0·31 volt.

In applying Langmuir's equation for electron current given above, it must not be forgotten that the cooling effect of the leads to the filament will decrease the electron flow from the ends of the filament and the design of the connections to the filament is therefore a matter of some importance.

Two other valve design considerations may be mentioned: they are the efficiency of emission of electrons from the filament and the useful life of the valve. Richardson's equation shows that the emission of electrons depends on the temperature of the filament; the emission at a given temperature can be increased by depositing limes on the filament surface, but this generally means that a greater heating current is required to give the same temperature.

Comparisons of temperature for a given watts input can be made by photometric methods.

The life of a valve coincides in most cases with the life of its filament; if the latter is overrun to get a good emission of electrons the life will be short. In commercial work the life is probably a matter of greater consideration than the filament efficiency; it is for this reason that in the comparisons given above the valves have been tested with filament currents for which they are guaranteed or with which they are likely to have a useful life.

QUESTIONS ON CHAPTER X.

1. Give an approximate calculation of the energy consumption of a Pliotron valve used on a wireless receiver.

2. What are the characteristic properties required in a valve which is to be used in a L.F. Amplifier? Briefly denote how it should be designed in order that it should give these properties.

3. One valve oscillates more freely, or with looser reaction coupling, than another. Briefly state the probable reasons.

4. Why should the electrodes in a valve be firmly supported ?

5. A valve requires a high plate potential in order to give a steep plate current characteristic. What is the probable reason ?

6. What are the probable characteristics of a valve in which the grid is very close to the filament and the plate very close to the grid ?

7. What determines the smallest size of filament suitable for a receiver valve ?

8. How will the characteristics of a valve be modified if it is re-designed : (*a*) with a grid of much finer mesh ; (*b*) with a grid of much coarser material ?

9. How can you ascertain if there is any ionic effect in a valve ?

CHAPTER XI

SPECIAL VALVE DESIGNS AND CHARACTERISTICS

Audions of the Western Electric Co.—The Western Electric Co., U.S.A., have designed and patented Audion valves in which the grid is extremely close to the filament, being only separated from it by a thin insulating film of nickelous oxide. The anode plate is placed very near the grid and filament so that good amplification is obtained with low plate voltages. In these valves the filament is wound over the grid so that the latter does not intervene between the plate and filament.

In small Audions of this design the grid is an inverted V-shaped loop of wire with a film of nickelous oxide on its surface, and the filament is wound in turns of wire on this grid. The plate consists of a rectangular sheet of metal at each side of, and close to, the grid and filament.

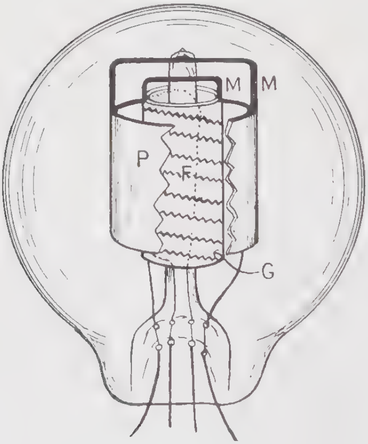


FIG. 111.

The design of this valve in larger sizes is shown in Fig. 111. Here the grid is a cylinder of metal (G) with the filament (F) over it and a cylindrical plate (P) surrounding them. The plate and grid are supported by metal arms (M) and (M) from a glass central supporting pillar.

In still larger sizes for transmission purposes the valve is made cylindrical, like a tube with a double glass wall, so that a tubular opening runs right through the centre. Through this a circulation of cold water or other liquid can be passed, so that the valve can handle large amounts of energy without danger of overheating.

In another type of large Audion made by this Company the plate consists of a long ribbon of metal, folded backwards and forwards, on both sides of the grid and filament. The idea underlying this construction is that the long strip plate has a higher resistance than ordinary sheet plates; therefore it can be raised to a high temperature with comparatively small currents to drive out occluded gases during the construction of the valve. The grid is a winding of wire on a glass rectangular frame inside the plate; the sides of this frame carry little metal hooks on which the filament is fixed inside the grid, being wound diagonally on the glass frame from the bottom to the top of the frame. The filament is connected so that there are three portions in parallel, in other words instead of being a long filament with a great potential difference between its terminals it really consists of three filaments in parallel.

Dynatron or Negative Resistance Valve.—If electrons strike against a positive, or plate, electrode with sufficient velocity they may cause other electrons to be shaken out of the material in the plate; this secondary emission of electrons from the plate constitutes what Sir J. J. Thomson called the "Delta rays," already referred to in Chapter II. If the velocity of the bombarding electrons is sufficiently great the number of electrons emitted by the plate may be much greater than that of the electrons which arrive at it, so that the effective electron, or current, flow in the plate circuit may be reduced, or even reversed by the action of this phenomenon. It has already been pointed out that the velocity of the arriving electrons depends on the plate and grid potentials, therefore the phenomenon of plate emission can be controlled by a proper adjustment of these potentials. In an ordinary valve the electrons emitted by the plate are generally drawn back again into it, because its positive potential is much higher than that of any electrode, such as grid or filament, near it; if, however, the grid potential is made highly positive compared to that of the plate the emitted electrons may be attracted to the grid.

Thus it can be arranged that a proportion of the electrons radiated from the filament pass through the grid to the lower potential plate, striking the latter with such a velocity that it emits electrons which are drawn to the grid.

If, now, a plate circuit characteristic curve is taken in the ordinary way, with a fairly low positive plate potential, the current will rise to saturation and then begin to decrease again with increasing positive potential applied to the grid.

Dr. A. W. Hull first drew attention to the possibilities of a valve designed and connected up so that this action was accentuated; his valve is made by the General Electric Co., U.S.A., and is now known as a *Dynatron*. It may be employed to limit the strength of jamming signals, to generate oscillations, or to introduce a negative resistance effect into an oscillating circuit. Since the control electrode has to stand electron bombardment and carry comparatively heavy currents, it must be more massive than the grid of an ordinary valve.

In any valve the saturation value of plate current can be reduced to a low value by reducing the filament temperature, though this is generally accompanied by a bad slope of curve which means poor rectification on weak signals; it can also be limited by adopting a suitable design of valve, as in the case of the Marconi Q and V. 24 valves. By modifying the design, using a fairly coarse grid of fine mesh, a characteristic curve as shown in Fig. 112 may be obtained, with suitable adjustment of filament temperature. If the valve is made to function at the point a it is seen that both halves of an oscillation of grid potential cause a decrease of plate current, *i.e.* both positive and negative halves of oscillations will be rectified. At the same time a limit is placed on the strength of the consequent current pulse in the plate circuit, and this can be used to ensure that the pulses caused by atmospherics or strong local jamming are not stronger than the signals it is desired to read.

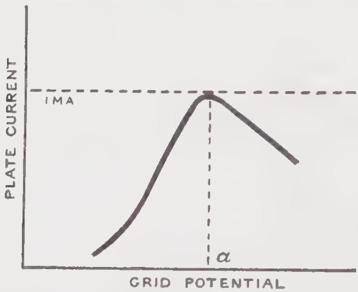


FIG. 112.

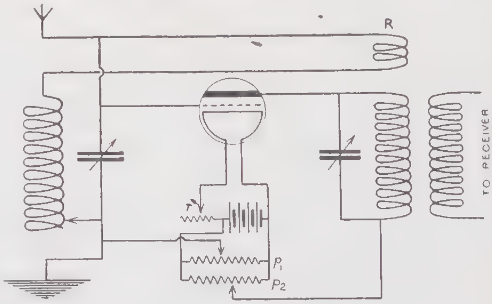


FIG. 113.

A method patented by the Marconi Company and F. P. Swan for the use of a valve as a limiter is shown in Fig. 113. The potentiometers p_1 and p_2 adjust the potentials of the grid and

A General Electric Co.-Hull dynatron is shown in Fig. 116: the filament is a spiral of tungsten wire, the anode or grid is a spiral of stout wire, and the plate a cylinder of metal.

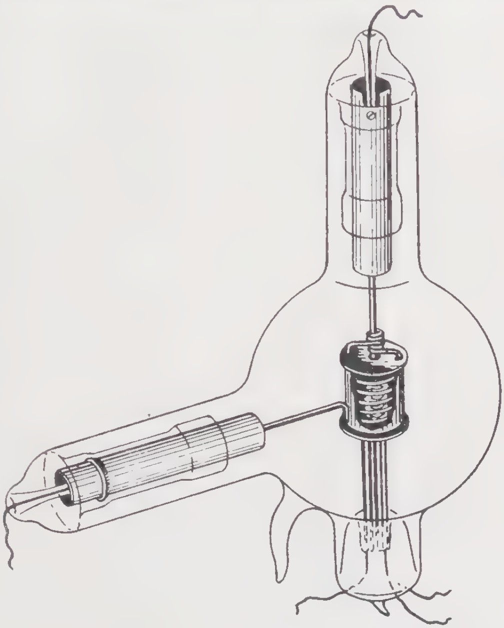


FIG. 116.

In the British patent No. 114539 (1918) of the British Thomson Houston Co., acting for the General Electric Co., Schenectady, the use of a dynatron as an amplifier, or detector, or both, is very clearly described. The plate current curve is seen in Fig. 117, the point G on the curve being the value of the plate current when the plate potential is equal to that of the anode grid. By properly designing the valve the portion BD of the curve can be nearly a straight line.

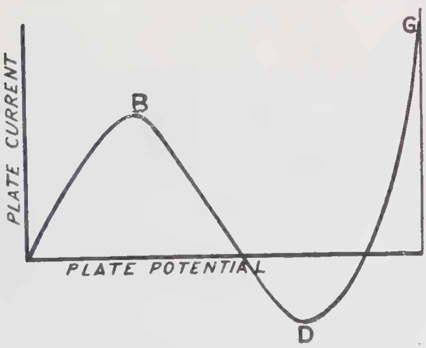


FIG. 117.

As an amplifying detector the dynatron is connected up as shown in Fig. 118, and the potentials adjusted so that the valve functions on some point near B or D on the portion BD of the curve. Since B and D are rectifying bends on the curve the valve will then act as a detector; since it is functioning on the portion BD of the curve it will introduce a negative resistance effect (r) into the circuit. The damping factor of the circuit is $\frac{R}{L} - \frac{1}{Kr}$, where R is the

positive resistance of the circuit, L its inductance, and K its capacity. This damping factor equals zero when $Rr = \frac{L}{K}$.

Owing to the tendency of the valve to generate oscillations, *i.e.* when Rr is less than $\frac{L}{K}$, the high inductance of the telephone receivers might make these oscillations occur at audible frequency, and therefore interfere with the reception of signals. The condenser K_1 across the receivers, if properly adjusted, will prevent this; its value may be also adjusted in combination with that of the valve negative resistance effect to make the receivers most sensitive

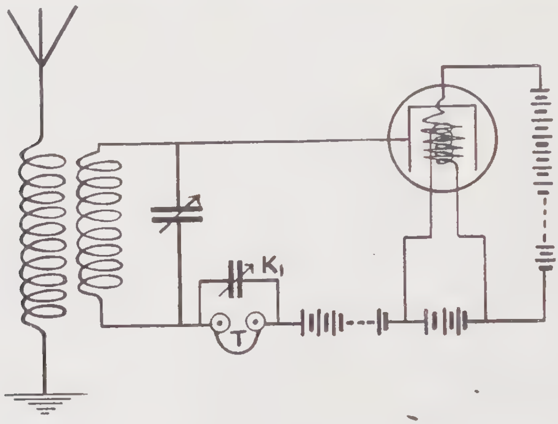


FIG. 118.

for a given audio frequency. This particular audio frequency can be that of the signals it is desired to receive, so that the sensitiveness may be greatly increased by using K_1 to bring the telephone circuit into resonance.

If the damping factor $\frac{R}{L} - \frac{1}{Kr}$ is negative, in other words if the negative resistance effect is such that Rr is less than $\frac{L}{K}$, the valve generates oscillations. The circuit can be tuned so that the frequency of these is slightly different from that of the received oscillations; the latter are then heterodyned. Thus the arrangement can be used to receive C.W. signals.

The advantage claimed for this system is that it enables a

closer coupling than usual to be employed between the aerial and closed circuits, without sacrificing selectivity or reducing sensitiveness, since the damping effect is negligible and the sensitiveness is therefore independent of coupling, as it is also of resistance.

The dynatron may be employed only as an amplifier to neutralise the positive resistance of the receiver circuit, reduce the damping, or, in the case of C.W. reception, set up local oscillations. In this case a second valve, or valve system, would be employed for rectification. One method of making up a receiver circuit on these

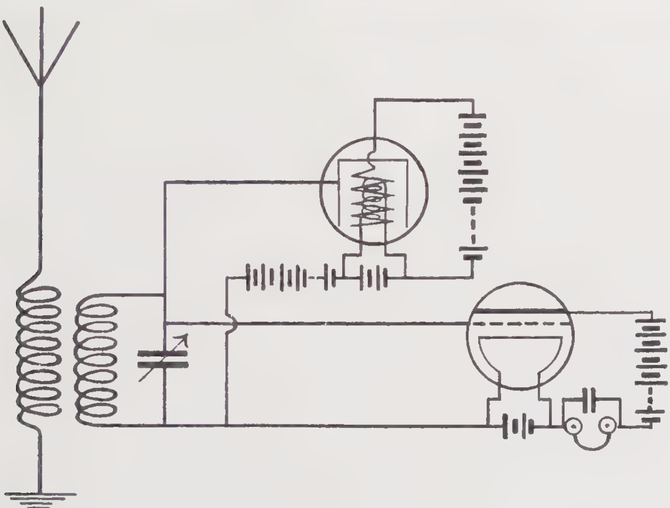


FIG. 119.

lines is shown in Fig. 119. It may be noted that the dynatron will now reduce the damping due to grid circuit current in the rectifying valve, as well as that due to positive resistance of the receiver circuit.

It is evident that the dynatron may be inductively coupled to the receiver circuit instead of being directly coupled as shown in Fig. 119. The detector valve may require a potentiometer in the grid circuit, and a telephone transformer may be employed in the usual manner.

With the design of dynatron made by the General Electric Company it is possible to stop the reversal of plate current, at higher plate potentials, by subjecting the current in the valve

to a longitudinal magnetic field. This has the effect of distorting the electron flow so that it follows an oblique or curved path outwards from the filament, and very few electrons get through the grid anode. The secondary emission from the plate is therefore diminished and the plate current-plate volts curve will be as shown in Fig. 120, where it is the curve of continually increasing current, whereas the normal dynatron curve (shown dotted) rises to a maximum and then falls.

Four-Electrode Valves used as Limiters.—With varying grid potential the plate current of a valve can vary between zero and its saturation value; the latter can be reduced by reducing the filament temperature, and with low filament temperature the possible variation of plate current is very limited, having the same range for small or large variations of grid potential. This action can be employed to limit the effect of strong atmospherics, or of local signals, in a valve amplifier or detector; unfortunately, however, a reduction of filament temperature is generally accompanied by a decrease of the slope of plate current characteristic, thereby decreasing the sensitiveness of the valve.

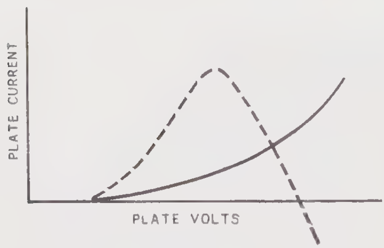


FIG. 120.

The Marconi Company and G. M. Wright have patented a valve arrangement which acts as a limiter and in which the valve itself has a second, or auxiliary, grid. A diagram of the circuit proposed is shown in Fig. 121; the valve filament is used simply to supply a flow of electrons, and its temperature is adjusted to the usual suitable value by means of a rheostat. The oscillating circuit is connected to the grid G on one side and to the auxiliary grid G_1, through the potentiometer p_1, on the other, the potentiometer being used to adjust the potential difference between the two grids to the most suitable value. The tuned plate circuit is connected across the plate and auxiliary grid, and the oscillations set up in the plate current are handed on to the receiver through an inductive coupling. A reactance coil R is included in the primary oscillating circuit and is adjusted to balance out any accidental coupling that may exist between this circuit, or the

aerial circuit, and the plate circuit; such a coupling is likely to exist owing to the assembly of the apparatus in a case or panel, and if not neutralised atmospherics or strong signals would pass direct. The potentiometer p_2 adjusts the potential difference between the auxiliary grid and the filament. It is found that such an arrangement of valve and circuit limits the permissible change of plate current for change of grid potential, even with a filament whose temperature is not dulled.

It would be better if the valve were designed so that the potentiometers p_1 and p_2 were not necessary, as the insulation of the

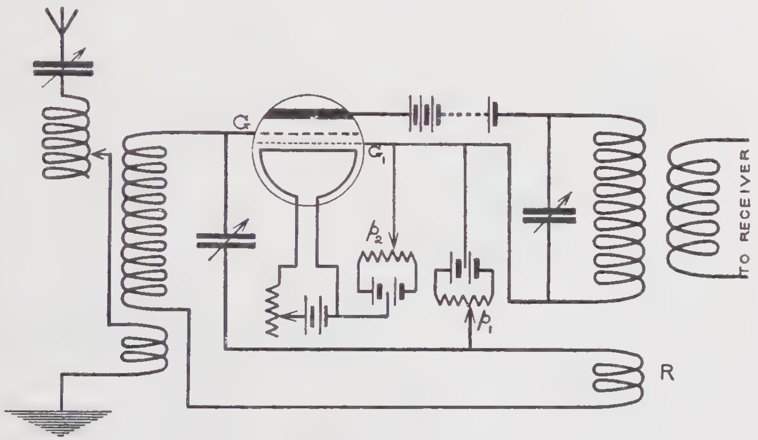


FIG. 121.

potentiometer batteries and their capacity effects to earth are likely to cause trouble.

A valve with auxiliary grid can also be used as a limiter behind the receiver and detector by employing it as one of the valves in a L.F. Amplifier. They should also prove useful in L.F. Amplifiers employed as receivers in earth current signalling, for they will limit the effects due to earth discharges and leaks from neighbouring lines which are always so troublesome. The Siemens and Halske two-grid valve shown in Fig. 107 is used in a L.F. Amplifier.

Pliodynatron.—The first four-electrode valve due to Dr. A. W. Hull and made by the General Electric Company, U.S.A.,

was called by them a *Pliodynatron*, since it is a combination of a pliotron and a dynatron. They used it as an oscillation generator in which the output is controlled by the control grid, which is between the filament and the heavier grid anode beyond, the latter being kept at a high positive potential. For example the potential of the control grid may be varied by speaking into a microphone coupled to the grid circuit through a transformer, so that the pliodynatron can be used for wireless telephony transmission.

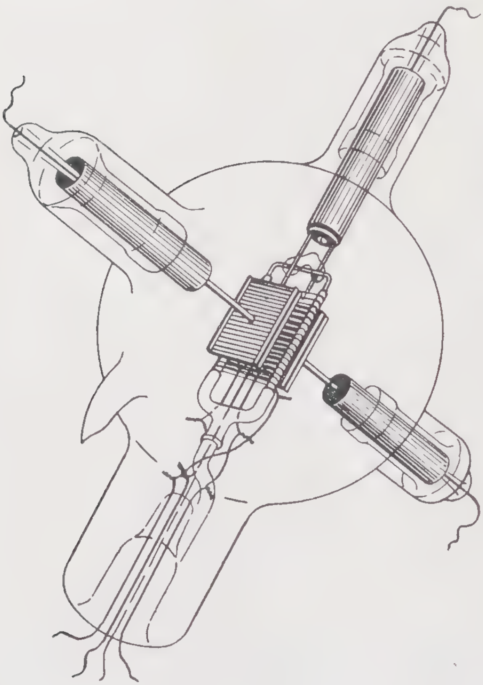


FIG. 122.

A view of a General Electric Co.-Hull pliodynatron, suitable for use as a transmitter generator, is shown in Fig. 122.

G.E.C. Valve with Two Plates.—A special four-electrode valve made by the General Electric Company, U.S.A., contains two plates and is employed by them as an amplifying valve for the microphone control currents in a radio-telephony transmitter. It derives its plate potential by an inductive coupling to a high potential point in the aerial circuit. With such a potential source plate current would flow in one plate valve only at each positive half cycle of potential induced by an oscillation in the aerial; the two plates are therefore connected to the circuit in such a way that they act alternately, one on a positive half cycle, the other on a negative half cycle. The use of this valve in a transmitter of radio-telephony is shown in Figs. 192 and 193, Chapter XV.

Western Electric Company Valve with Two Grids.—This valve is not a pliodynatron but is used as an amplifying valve for

the microphone control currents in a radio-telephony transmitter. If a valve is generating the plate current oscillations will be full and staple when the valve has a negative potential on the grid. An increase of this negative potential may stop the oscillations, a reduction of it makes the valve function farther up its characteristic curve and reduces the amplitude of the oscillating energy. Thus it is not good practice to use a valve to generate oscillations and at the same time modulate the oscillations by acting on the grid potential with microphone currents. If a valve has two grids one can be used to fix the point of functioning, the other can vary the plate current by modulating its potential with the currents in a microphone acting through a transformer. The use of this valve is shown in Fig. 194, Chapter XV.

Ordinary Three-Electrode Valve used as a Limiter.—G. M. Wright and the Marconi Company have patented an arrange-

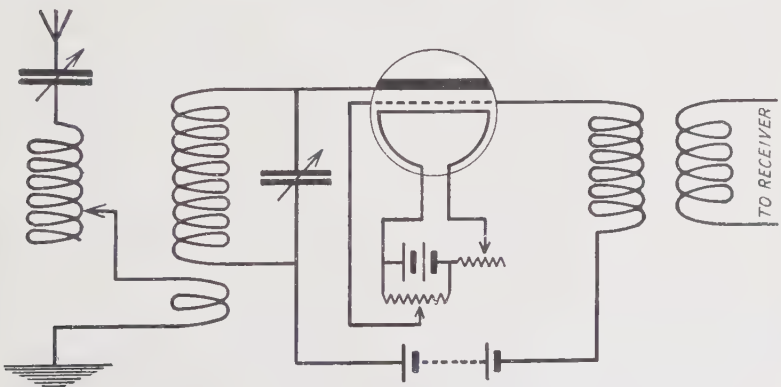


FIG. 123.

ment for employing a three-electrode hard vacuum valve as a limiter or as a limiting detector; in this method the oscillating circuit, instead of being connected across the grid and filament of the valve, is connected across the plate and grid. The valve employed should have a grid of fine mesh. The grid potential with respect to the filament is adjusted by means of a potentiometer, and the plate potential with respect to the grid is adjusted by means of a battery or potentiometer. Fig. 123 shows the connections when used as a limiter, the limiting effect on the plate current for changes of grid potential being shown in Fig. 124.

A method somewhat similar to this was used by De Forest in what was called the Ultra-audion Circuit; the oscillating circuit was connected across the plate and grid of the valve, the plate circuit was completed in the usual way from plate, through H.T. battery and telephone receivers, to the filament, but there was no circuit between the grid and filament. The audion was thus employed as a detector as well as a limiter.

Valve with Electrically Deposited Plate.—When an electric lamp is overrun, so that the filament is raised to an excessive temperature, it may be noticed that the surface of the filament vaporises, and the vapour condenses as a deposit of tungsten or carbon (depending on the filament used) on the inside of the globe. Dr. Langmuir has lately shown that a similar process may be adopted for forming the plate of a hard valve. A filament of more

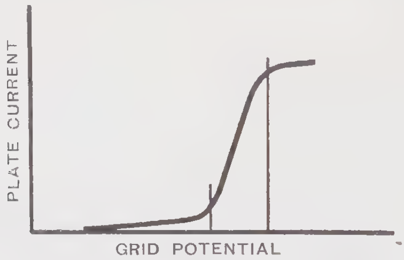


Fig. 124.

than the required thickness is mounted, together with the grid, as usual in a glass tube or globe; the latter is then exhausted to a vacuum. The filament is now raised to a high state of incandescence by passing a current through it; the filament surface vaporises and the particles of vaporised metal condense to form a very fine coating on the inner surface of the globe. This forms the plate to which a connection may be made by sealing a small piece of platinum wire through the glass. In order to prevent the vaporised metal from being deposited across the glass where the filament and grid leads enter, and shortcircuiting them, glass knobs or screens must be mounted in front of these points; the vaporised metal issues out in straight lines and cannot pass round a glass obstruction.

This construction would seem to be very suitable for a receiver valve since it gets over any trouble caused by inequalities of the

metal consignments used in plate manufacture, and eliminates the occlusion of gases in the plate.

QUESTIONS ON CHAPTER XI.

1. What is meant by a limiting valve, and how does it act ?
2. How does a Dynatron differ in design and use from an ordinary hard vacuum valve ?
3. How would you use a Dynatron to amplify signals ?
4. What is a Pliodynatron valve ?
5. To what uses can valves be put which have got—
    (*a*) two grids ;
    (*b*) two plates ?
6. How can an ordinary three-electrode valve be used as a limiter ?

CHAPTER XII

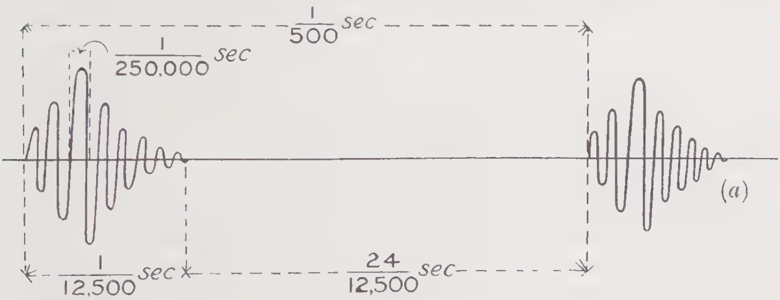
CONTINUOUS WAVE TRANSMISSION

The generation of oscillations in the circuits of a valve has already been described in Chapter V.; it was there explained that the oscillations were undamped, had an amplitude depending on the potentials applied and the electrical constants of the circuits, and a frequency which may be that of the plate or of the grid circuit, but which, in either case, will vary slightly as the coupling between the valve circuits is varied.

Advantages of Valve C.W. Transmission.—Oscillations can be induced in an open, or radiating, circuit suitably coupled to the valve circuit. The oscillations differ from those set up by the discharge of a condenser across a spark gap in that they are undamped, or sustained, so that each resulting wave in the ether will carry off as much energy as the one that preceded it. The loss of energy from the ether waves as they are propagated through space will occur with C.W. transmission in the same manner as with spark transmission.

Suppose that spark transmission is taking place on a 1200 metre wave at a spark-frequency of 500 per second; the oscillation frequency is $\frac{v}{\lambda} = \frac{3 \times 10^9}{1200} = 250{,}000$, and there may be 20 oscillations in the aerial at each spark. The amplitude of the oscillations at each spark will diminish towards the end of the train, involving a decrease in the rate of energy radiation. The conditions for the duration of two spark discharges will be as shown in Fig. 125 (*a*). Supposing that there are 20 oscillations per spark; in each period of $\frac{1}{500}$ second rapidly diminishing energy is radiated during $\frac{1}{12500}$ second and none at all during the remaining $\frac{24}{12500}$ second. On the other hand, if the oscillations are generated by a valve on the same wave length the conditions are as shown in Fig. 125 (*b*); the energy amplitude of each wave with the valve may be smaller than the maximum one with the spark generator, but there is no time space

of idleness, and the total energy radiated in a given time may be greater for the same amount of applied primary energy. The effect on the distant tuned receiver is more persistent and all the energy is on one wave length, whereas in a spark system the energy is carried on a number of wave lengths. This partly accounts for the fact that the ranges obtained with undamped radiation are much greater than those of a spark system; but the primary energy of a C.W. station can be smaller than that of a spark transmitter and yet the range will be greater, chiefly on account



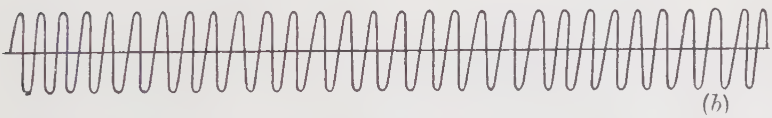


Fig. 125.

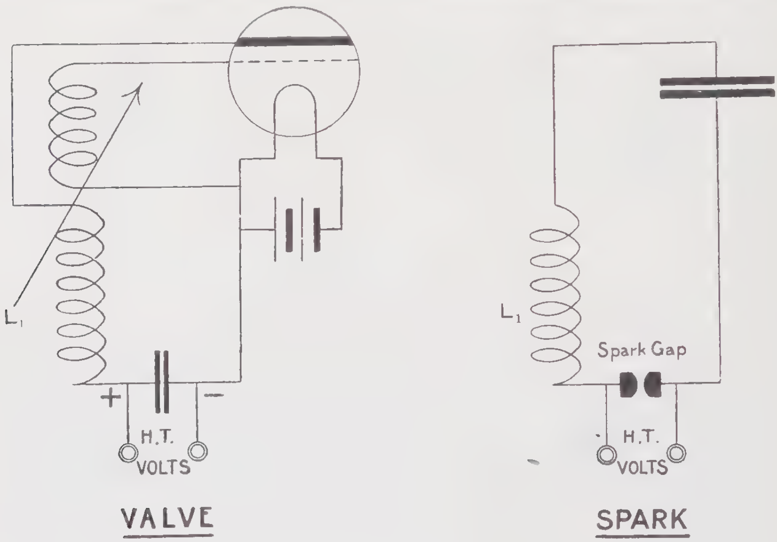
of the more favourable conditions at the receiver as will be hereafter explained.

A comparison of the circuits for generating electrical oscillations by the valve and spark methods is shown in Fig. 126; in either case energy is transferred to an aerial circuit by coupling it to the inductance L_1 so that the oscillating currents in L_1 induce oscillating potentials in the aerial circuit.

Another great advantage of undamped oscillations is that they can force a short aerial to radiate energy on long wave lengths; for example, with 6 volts on the filament and 400 volts on the plate on a receiver valve of French design, an aerial 20–30 feet long and 15 feet high can easily transmit on wave lengths of 1000 metres, or more, over a range of 10 to 15 miles, to a receiver aerial 40 yards long and 15 feet high.

When a short aerial is connected to the top of the coil L_1 in Fig. 126 (*a*), and an earth to the bottom, the aerial and earth act as a small condenser ; each pulsation of current in L_1 will induce an oscillating E.M.F. in it which is applied to this condenser, so that oscillating charge and discharge currents flow in the aerial-earth circuit and energy is radiated. The value of the oscillating current in the aerial will depend on its capacity so that it will be smaller the shorter the aerial.

A third advantage which C.W. transmission possesses is that



(*a*) (*b*)

Fig. 126.

the potential strains in the aerial are much smaller than those required in a spark transmitter of the same output ; this simplifies the insulation required for the aerial and reduces the probability of serious leakage or brush discharge losses.

Lastly, it is possible to have a number of C.W. stations in close proximity to each other working on wave lengths which differ by very small percentages without risk of jamming. When we say that a spark transmitter is working on 600 metres wave length we do not mean that all the energy radiated from it into the ether is on that wave length. Even with accurate tuning, loose coupling, and quenched closed circuit, the energy will probably be carried away on all wave lengths between 570 metres and 630 metres. To

say that the station is working on 600 metres means that *most* of the energy is radiated on that wave length, but there is also a considerable amount of energy radiated on the neighbouring wave lengths. Therefore it is not possible to have receiving stations working in the vicinity of a spark transmitting station without strong jamming, even when there is a great difference in the wave lengths of the transmitting and receiving stations.

With C.W. or undamped wave transmission all the energy is radiated at one definite frequency or wave length, neglecting a small amount which will be carried on harmonics but will not penetrate very far. The percentage difference of wave lengths, or frequencies, which can be employed at C.W. stations in close proximity to each other is therefore only limited by the difference of frequencies which will produce beats in the receivers. Up to a wave length of 1000 metres C.W. stations in close proximity to each other can employ wave lengths differing by only 5 per cent. without risk of interference.

Oscillating Currents in a C.W. Transmitter.—It may be advantageous to shortly review the oscillating conditions in the circuits of a generating valve suitably connected up and coupled. Let the circuits be as shown in Fig. 127, where M and M_2 are milliammeters in the plate and grid circuits respectively, whilst M_1 is a hot-wire milliammeter or ammeter in series with the condenser K_1. The filament is at a suitable high temperature and the plate potential high enough to cause strong oscillations.

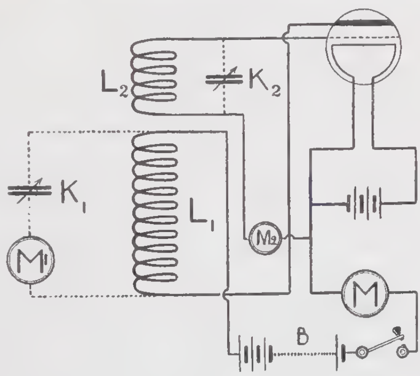


FIG. 127.

For the moment let us assume that the value of K_2 is zero and that the oscillating conditions are satisfied, in other words that $R + \dfrac{L_1 + FM}{K_1 r}$ is less than zero, or M is greater than $\dfrac{1}{F}(L_1 + K_1 rR)$ and is negative in sense. Here F is the voltage amplifying factor of the valve, R the external resistance of the plate circuit, r the valve plate circuit resistance, and M the coupling between the plate and grid circuits (see Chapter V.).

We have then four oscillating components of currents to consider an oscillating current in the grid circuit which is read on M_2, an oscillating component of current in the plate circuit whose mean value is read on M (assuming the plate current to oscillate between zero and saturation), an oscillating current in the plate coil L_1, and an oscillating current in the condenser K_1, which is read on M_1. The oscillating current in the plate circuit is the resultant of the oscillating currents in L_1 and K_1, these being in opposition of sign as far as the plate circuit is concerned. If K_2 has any value the oscillating current in the grid circuit is the resultant of two oscillating components in the coil L_2 and in the condenser K_2 respectively.

It must not be forgotten that the valve itself has got capacity effects which act in the plate and grid circuits in parallel with the condensers K_1 and K_2 respectively. For example, the wave length of the plate circuit will be a little greater than $59{\cdot}6\sqrt{L_1K_1}$ owing to the small additional and shunted capacity effect of the valve: perhaps also of the leads if these are long and close together. Similar reasoning applies to the grid circuit. Generally the oscillation frequencies of these two circuits are very different from each other, as can be ascertained by uncoupling them and measuring them independently.

The oscillations are sustained by the oscillating potentials induced in the plate and grid circuits through the mutual coupling, —M, between L_1 and L_2. If i_c is the oscillating current in the plate circuit coil, the induced potential in the grid circuit is $-M\frac{di_c}{dt}$ and its phase is 90° in advance of that of i_c. The oscillating potential induced in the plate circuit is $-\left(Ri_c+L\frac{di_c}{dt}\right)$ and it lags behind the phase of i_c by an angle $(90° + \theta)$, where θ is very small and $\tan\theta = \frac{R}{2\pi fL}$. Calling this oscillating potential v_c the oscillating current in the plate circuit capacity K_1 is $-K_1\frac{dv_c}{dt}$ and it is nearly in opposition to i_c, making an angle with the latter of $(180-\theta)°$ and an angle of 90° with the oscillating potential in the coil L_1.

Radiation Wave Length.—It may be recalled that when a closed oscillating circuit and an aerial circuit in a spark transmitter are tuned to the same frequency, and coupled together,

radiation takes place on two wave lengths, both of which differ from that to which the circuits are tuned by an amount depending on the degree of coupling. If the circuits are tuned to different frequencies and the aerial one has a high resistance it will be forced to oscillate at the frequency of the closed circuit; on the other hand, if the closed circuit has a high resistance the aerial circuit will have oscillations induced in it by shock, and will then oscillate at its own frequency. The latter conditions correspond most closely to practical working.

Now if the grid circuit of an oscillating valve has a natural frequency which differs from that of the plate circuit a question at once arises as to which will determine the frequency of radiation and the transmitted wave length. The question is most simply solved by experiment, and a description will therefore be given of results which were obtained in an experiment with an oscillating valve.

A circuit was made up as in Fig. 127; the wave lengths of the plate and grid circuits without K_1 and K_2, but with the valve filament heated and 100 volts on its plate, were respectively 280 and 425 metres. K_1 was now connected across the plate circuit, K_2 still left disconnected, and the wave lengths of radiation noted for various values of K_1 as shown in the table:—

K_1 in mmfds.	Wave length as measured by buzzing into plate circuit.		λ of radiation with sub-harmonics.	Remarks.
	λ of plate circuit without valve.	λ of plate circuit with valve connected—no reaction.		
0·1	435	510	**580**, 1160, 1740	Grid circuit kept constant, of wave length = 425 metres when not reacting.
0·2	670	690	**730**, 1460, 2190	The number of harmonics detected was limited by the range of the wavemeter.
0·3	810	825	**860**, 1720	
0·4	945	950	**980**, 1950	
0·5	1145	1160	**1190**, 2280	

A valve wavemeter was used to measure the radiated wave lengths.

The wave lengths in the third column were rather difficult to determine accurately owing to the damping effect of the valve. Thus when capacity effect preponderates in the plate circuit the wave length of radiation is governed by the tuning of the plate

circuit, and is a little higher than that of the plate circuit owing to the mutual induction effect.

Now keeping K_1 constant at 0·2 mmfd., corresponding to a plate circuit wave length of 670 metres, or 690 with the valve, K_2 was connected across the grid circuit and the radiated wave length noted as its value was varied :—

By buzzing across grid circuit.

K_2 in mmfds.	λ of grid circuit without valve.	λ of grid circuit with valve connected but no reaction.	λ of radiation with harmonics.
0·1	535	620	**770**, 1530, 2310
0·2	730	780	**810**, 1620
0·3	905	930	**890**, 1780
0·4	1040	1040	**930**, 465, 1940
0·5	1140	1140	**1050**, 520, 1000, 2120
0·6	1330	1330	**1140**, 570, 1720, 2300

The first value of radiated wave length, when the grid circuit capacity was still relatively small, was probably governed by the plate circuit ; for the higher values of grid circuit capacity the radiated wave length was governed by the tuning of the grid circuit, and the effect of mutual induction and reaction capacity made it always less than the wave length of the grid circuit.

Now what will happen if the plate and grid circuits are almost in tune ? Will the radiated wave length be something longer than that of the plate circuit or shorter than that of the grid circuit ? And when they are exactly in tune will the radiated wave length be above or below that of the tuned circuits ? With the valve lit and 100 volts on the plate the circuits were uncoupled and each tuned to 920 metres ; K_1 was then 0·38 mmfd. and K_2 was 0·28 mmfd. ; the radiated wave length was found to be 1020 metres, with harmonics at 510, 2040, and a very weak one at 1530 metres. On decreasing K_1 to 0·34 mmfd., the plate circuit wave length being now 900 metres, the radiated wave length fell to 1000 metres, and further decrease of K_1 to 0·3 mmfd. reduced the radiated wave length to 965 metres ; *also by listening in on the wavemeter telephones it was noted that the wave length was very susceptible to slight changes of K_1.*

On the other hand, when the grid circuit condenser was varied from 0·28 to 0·15 mmfd. the wave length only fell to 1000 metres, and when raised to 0·3 mmfd. the wave length was 1050 metres ;

also the note in the wavemeter telephones could be heard over a comparatively wide range of the grid condenser, showing that the radiated wave length was not very susceptible to a change of grid circuit tuning. That the grid circuit tuning would make a slight difference in the wave length was to be expected since it changes the grid current and therefore the mutual induction. Thus it is evident that in this case the wave length is controlled by the plate circuit.

Now the circuits were interchanged so that L_1K_1 were in the grid circuit, and L_2K_2 in the plate circuit, and it was noted that again the tuning was sharper on the plate circuit condenser than on the grid circuit condenser.

Lastly the plate circuit capacity was reduced to a minimum by disconnecting K_1 and the wave lengths noted for various values of the grid circuit condenser :—

K_2 in mmfds.	Wave length of grid circuit by buzzing with the valve connected up.	Wave length of radiation with harmonics.
0·1	580	**610**, 1180, 1770
0·2	740	**710**, 1380, 2070
0·3	900	**835**, 1650

Therefore it is evident that in this case the frequency of radiation is governed by the tuning of the grid circuit.

Thus we are led to the general conclusion that the frequency of radiation will be determined by that circuit in which there is a relative preponderance of capacity effect, provided this is not too large to make the pulsing current in the circuit relatively small ; when the two circuits are almost in tune with each other the wave length of radiation is determined by that circuit in which the heaviest currents are oscillating, which is generally the plate circuit.

In connection with the above results it may be mentioned that it is very useful to observe the harmonics as well as the fundamental wave length ; they check the accuracy of observation, and it is often easier to adjust the wavemeter accurately to the silent point on a long wave length, corresponding to a sub-harmonic of frequency, than to one on the fundamental wave length.

It has already been shown, in Chapter V., that where the capacity of the plate circuit is appreciable the oscillations in it are limited by the limiting value which the plate current attains,

and when the capacity is small the amplitude of the oscillations is limited by the value which the induced plate potential attains.

Again it may be reiterated that the oscillations are set up by the variations of grid potential, therefore they will be of large amplitude only when the maximum positive swing of grid potential corresponds to a large plate current. This means that the valve curve of plate current varying with grid potential must be a steep one; as shown elsewhere this steepness of curve, for given plate potentials and filament temperatures, depends on the design of the valve.

In Chapter V. it has been pointed out that the amount of plate circuit inductance mutually coupled to the grid circuit must not be too great, else the oscillations of plate current will be limited by a drop of its saturation value at positive grid potentials. This result must not be overlooked, especially when working on high frequencies, *i.e.* short wave lengths. In some transmitters the plate is connected to the plate circuit inductance by an adjustable connection, so that the inductive coupling with the grid circuit may be varied to suit the frequency, or wave length. The plate should then be connected to a point in the aerial inductance where the potential value during oscillations is fairly high.

When a short aerial is employed this may lead to a curious result. If the inductance included in the plate circuit is small it will be necessary to increase the degree of coupling in order to give it a suitable value for sustaining oscillations of good amplitude. Thus the coupling will have to be tightened or the grid coil given a greater inductance value; in either case the capacity effect in the grid circuit will be increased. The short aerial means that the capacity effect in the plate circuit is small, and it may thus arise that the grid circuit will control the frequency and wave length. In transmitters fitted with a plate tapping it may occur that, with an adjustment of the tapping and coupling which gives a satisfactory aerial current, the wave length suddenly changes from that of the plate circuit to that of the grid circuit, and it may even happen that surging is set up.

This consideration must be borne in mind when designing a transmitter which will work efficiently over a long range of wave lengths; in any case the efficiency of a transmitter will greatly depend on the proper proportioning of the coupled induction effects in the plate and grid circuits; suitable values of these will be determined by the capacity of the aerial it is proposed to use.

Now if either of the condensers K_1 or K_2 in Fig. 127 is made open type, in the form of an aerial-earth circuit, the results already discussed hold good, therefore in such a circuit we shall obtain oscillating currents, and energy will be radiated into the ether. The ohmic resistance will be increased so that the oscillating current will be reduced for a given capacity effect.

It is more usual in practice to have the coil of highest inductance in the plate circuit of the valve; the plate potential will be high and the characteristic curve steep, so that a great induced variation of grid potential is not required to oscillate the plate current from zero to saturation. The largest oscillations of potential will then occur across the plate circuit coil, and if the aerial-earth circuit is connected across it the oscillating currents in this circuit will be greater than if it were connected across the grid circuit coil.

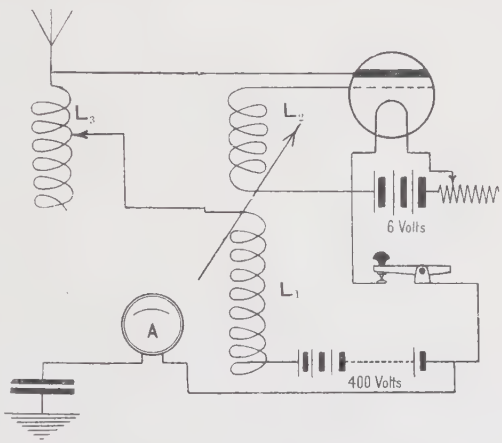


Fig. 128.

Thus a small C.W. transmitter of simple form can be arranged as shown in Fig. 128. The manipulating key is shown in the plate circuit; it is obvious that it might be placed in the aerial circuit, but in that case the H.T. battery would be supplying current to the valve circuit even when the key was open and no transmission taking place. Also the key would then be manipulating comparatively heavy currents which would wear away its contacts unless a special shunt is arranged across it.

Other positions of the key will be noted in the subsequent description of various C.W. transmitters. The hot-wire ammeter A, which shows the maximum value of aerial current, is sometimes replaced in small sets by a lamp which is lighted up by the current. It is generally preferable to connect a condenser in the aerial circuit between the hot-wire ammeter and earth or above the coil L_1, and to have a condenser shunted across the H.T. battery.

Tuning to different wave lengths could be made by tappings on the coil L_1 and coil L_3 omitted, but variation of the value of L_1 will also vary the degree of coupling between L_1 and L_2, therefore it is better practice to have separate coupling and tuning coils connected in series in the plate circuit, as shown in Fig. 128.

Instead of coupling the plate and grid circuits by means of the coils L_1 and L_2 they may be auto-coupled by taking a tapping from the plate coil to the grid; this method has been described in Chapter V., and for small transmitters it has the advantage that with it there is no possibility of having the reaction reversed. These modifications with several other elaborations will be more fully dealt with in the next Chapter, dealing with actual Valve Transmitters.

It is essential to keep the ohmic resistance of the aerial circuit as low as possible; this implies that the earthing or earth capacity must be carefully installed. The author has seen the aerial current of a C.W. transmitter, which had a mediocre buried earth, raised from 2 amperes to 4 amperes by simply connecting up an extra earth mat.

As remarked before it is not generally the case, with smaller sets at least, that the aerial-earth circuit is a tuned circuit coupled to the oscillating circuit; the aerial is generally much shorter than that required to give a natural wave length approximating to the desired transmission wave length. Thus the aerial-earth circuit as shown in Fig. 128 may be simply considered, not as a tuned or tunable circuit, but as an open condenser shunted across $(L_1 + L_3)$, in which currents are oscillating at a frequency determined by the inductance of $(L_1 + L_3)$, the mutual inductance between L_1 and L_2 and the capacities of the aerial-earth and of the valve in parallel.

Using an ordinary French valve of the receiver type, and the voltages as shown in Fig. 128, to transmit on a wave length of 1000 to 1600 metres the aerial may be about 60 yards long and 20 feet high. With an amplifying receiver it is then easily possible to transmit over a range corresponding to one mile for every $\frac{1}{10}$ watt supplied by the H.T. battery. A 50 watt transmitter may have an aerial which does not emerge from the house in which it is installed; it may be run along the rafters or ceiling of the garret and down the stairs to a lower room. With such an aerial arrangement it is possible to receive good signals on an outdoor aerial over a range of 50 miles.

By suitably connecting valves in parallel the generated oscillations and the oscillating energy in the aerial are increased in amplitude, with consequent longer ranges of signalling. By connecting a number of large transmitting valves in parallel satisfactory telephonic communication was first initiated in 1915 from Tuckerton in New Jersey to the Eiffel Tower in Paris.

For the transmission of wireless telephony it is only necessary to modify a C.W. transmitter in such a way that the oscillations are not broken up into Morse groups by a key, but have their amplitudes varied by the speech pulses in a microphone.

Probably the simplest method of transmitting speech, using a small valve transmitter, is to do away with the key in Fig. 128 and replace the aerial ammeter A by a suitable microphone. Speaking into the microphone will then cause variations in the resistance of the aerial circuit, so that the aerial current oscillations are modified in amplitude corresponding to the sounds affecting the microphone.

The oscillations and radiations are no longer continuous or undamped, but trains of waves of varying amplitude are radiated through the ether in much the same way as trains of waves are radiated at the spark frequency of a spark transmitter. Just as the distant receiver in spark signalling receives a note corresponding to the spark frequency so here the waves set up in the ether at the receiver will reproduce speech frequency, and therefore reproduce the sounds spoken into the microphone.

Thus the transmission will have more or less the same properties as those of spark signalling, and the ranges will be similar ; in other words wireless telephony ranges are very much smaller than if the same valve transmitter were used for ordinary C.W. transmission. The advantages of heterodyne reception cannot be utilised to the same extent as for C.W., so that the range of radiotelephony is about half that of C.W. working for the same energy.

There are better methods of connecting up a valve transmitter for wireless telephony ; these will be dealt with in Chaps. XIII. and XVI., where practical forms of transmitter apparatus are described.

Transmitter Valves.—For transmission purposes special valves have been designed, with very high vacua to withstand high plate voltages, and electrodes large enough to deal with the resulting energy flow. For small outputs the ordinary size of receiving valve (French type) can be used for signalling over ranges of 50 miles or more, depending on the height of the aerial and the sensitiveness of the receiving apparatus.

The characteristic curve of a large Pliotron valve, taken from a 1915 paper by Dr. Langmuir, is shown in Fig. 129, the plate potential being 8500 volts. Since the grid is at negative potential the grid circuit current will be small. The valve can control as much as one kilowatt of energy and has been employed on wireless telephony transmission. This Pliotron valve is shown

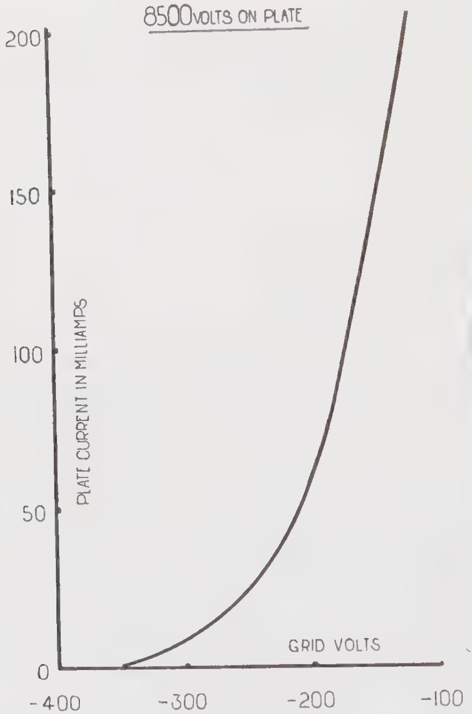


Fig. 129.

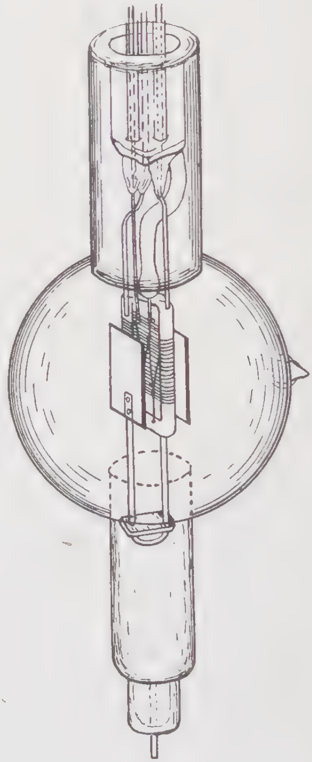


Fig. 130.

in Fig. 130. In the preceding Chapters an explanation was given of the generation of oscillations in a valve, with applied potentials corresponding to reception conditions, the plate currents under oscillating and non-oscillating conditions being illustrated in the Figures 73 and 75.

For transmission the filament temperature is preferably increased as well as the plate potential, the limits of increase

depending in both cases on the design of the valve as regards filament diameter, hardness of vacuum, and distance between the electrodes.

The construction of a valve designed by Round (Marconi Patent No. 28413–13) is shown in Fig. 131. There were three lime-coated filaments, so that when one burnt out another could be used; the filaments were comparatively thick, and were heated by a 6-volt battery in

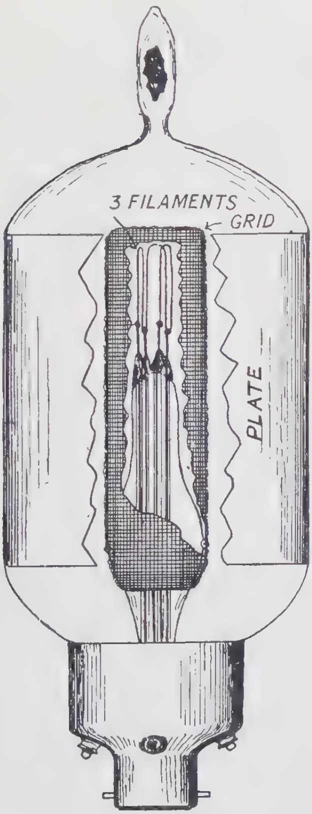


Fig. 131.

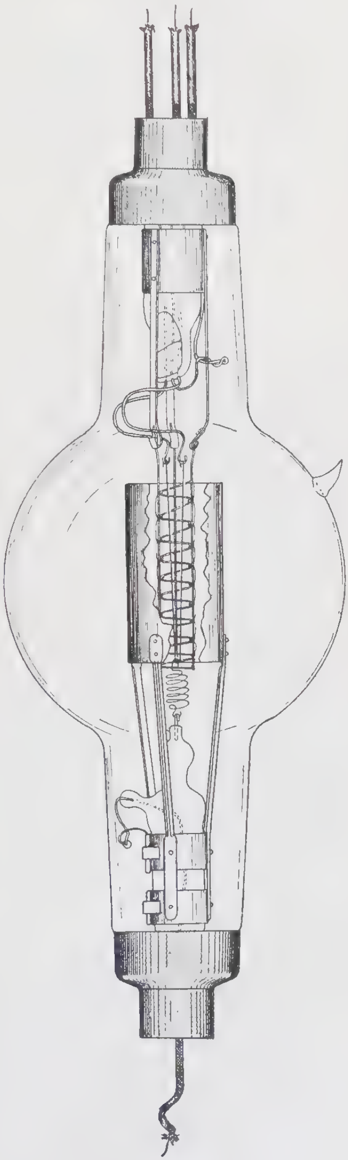


Fig. 132.

series with a regulating rheostat, the filament current being about 4 amperes. On account of their comparatively massive design the filaments were not easily broken by mechanical shock, and the life of a valve was very long.

The grid was of the usual Round pattern close nickelwire mesh held on a wire stiffening frame and completely enclosing the filaments. The plate of nickel sheet was placed close to the glass, an

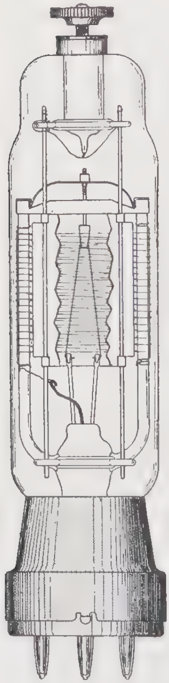


Fig. 133.

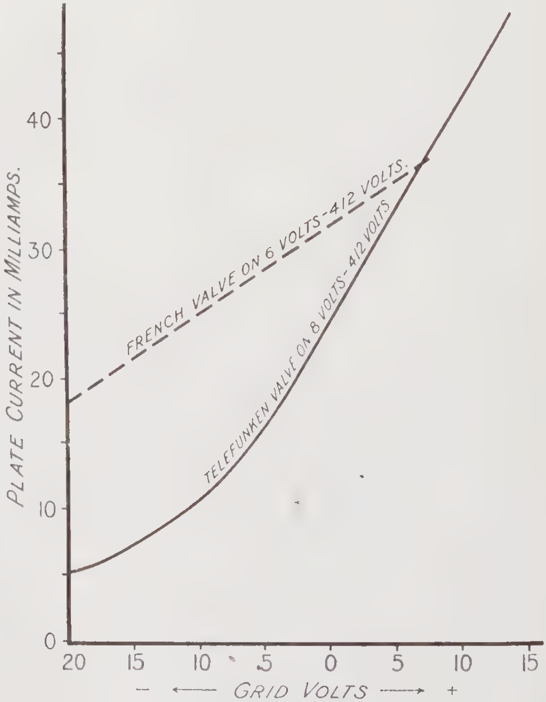


Fig. 134.

advantage of this arrangement being that the heat generated when large energies are handled radiates away quickly. By immersing the valve in oil heat radiation can be assisted, and the energy controlled by the valve increased without risk of damaging it, whereas the immersion in oil of a valve of French design would not increase the dissipation of heat to any extent. A disadvantage of placing the plate close to the glass is that it is farther removed from the filament, hence the resistance in the plate circuit is very

high. This necessitates the use of high plate potentials, and values as great as 15,000 volts may be employed. On these high potentials the characteristic curve of this valve was very steep.

The valve could be used to induce as much as 5 amperes of oscillating current in the aerial without undue heating. By designing the valve with the plate closer to the grid and filament it is probable that its energy efficiency would be increased without modifying the shape of its characteristic curve. The latter would be moved over from the region of negative grid potential to that of zero or positive potential, and the necessary plate voltage would be reduced.

Excessive currents in the grid circuit were avoided by connecting a high resistance, of the order of 10,000 ohms, in series with it, or by applying negative grid potential, or both.

Fig. 132 shows the construction of a valve made by the Gen. Elec. Co., England, for experimental purposes. It is practically an enlarged design of French valve, of very rigid construction, the filament requiring 15 volts to light it and taking about 1·95 amperes. The normal plate voltage employed is 800 to 1000 volts and under these conditions 1 ampere of oscillating current can be obtained in the aerial. A later and larger G.E.C. valve, which has given good results, is shown in Fig. 152.

A transmitting valve made by the Telefunken Co. is shown in Fig. 133 ; it is of Audion design and requires a filament current of 3 amperes on 8 volts. On a plate potential of 400 volts it can oscillate about 1 ampere of current in an aerial of suitable capacity. The internal construction of the valve is very neat and it gives a good characteristic curve, as shown in Fig. 134. This curve was taken with a filament current of 3 amperes and a plate potential of 412 volts. The curve is much steeper than that given by a French type valve of receiver size ; it is also farther over in the region of positive grid potential. The advantage of the latter is that with zero grid potential the plate current is comparatively small so that there is little necessity to use a grid circuit battery. This result is due to the fineness of the grid mesh and its comparative closeness to the filament.

The curves of a French valve (Metal type, receiver size) under transmitting conditions, with 5·8 volts across the filament and 400 volts on the plate, are shown in Fig. 135.

The aerial used was 50 yards long with an average height of 30 feet. An examination of the curves shows that, with zero potential applied externally to the grid, the plate current under

oscillating conditions is a little higher than when not oscillating, *i.e.* 43 milliamperes as compared with 37·8 milliamperes; thus the oscillations are not symmetrical in the positive and negative directions and a certain amount of rectification is taking place. The oscillations would be symmetrical where the curves cross, with about 8 volts positive applied to the grid, but the aerial current may drop rapidly at this point owing to the softening of

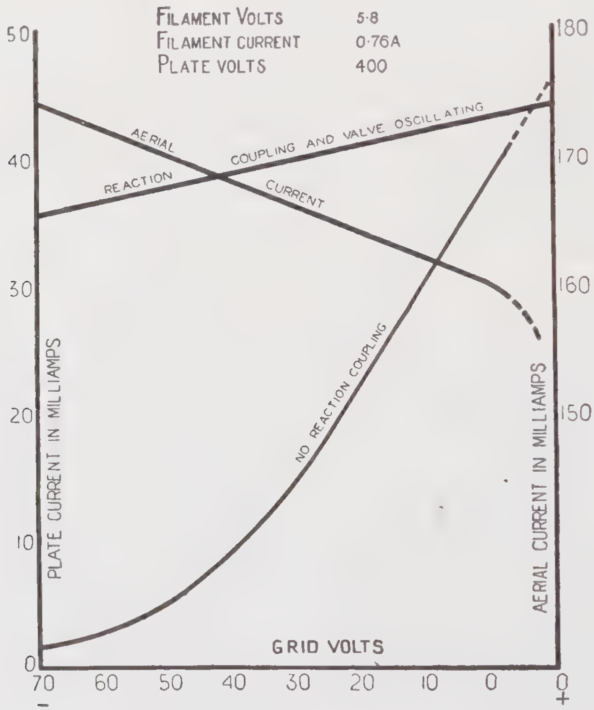


FIG 135.

the valve with the high value of plate current. It must be remembered that this valve was not designed for transmitting conditions. The curves show the advantage of applying negative potential to the grid; as this negative potential is increased, the current drawn from the H.T. battery to the plate decreases while the current oscillating in the aerial increases. With a negative grid potential of a value between 50 and 70 volts the plate current oscillations are almost entirely rectified, and the aerial current

rises to a maximum. With less negative potential on the grid the plate current oscillations will not be entirely rectified, the lower halves of the oscillations will have flattened tops, where the plate current falls to zero owing to the negative grid voltage induced, and this will lead to the introduction of a third harmonic in the oscillation wave.

The advantage of applying negative potential to the grid, thereby decreasing the plate current and increasing the aerial current, will be greater for higher plate voltages.

In the experiments with which the curves of Fig. 135 were taken, the valve ceased to oscillate and the plate current fell to zero when the negative potential on the grid was raised to 74 volts.

A small Q type Marconi valve with 6 volts on the filament and 300 volts on the plate will give 100 to 120 milliamps. of aerial current, and can be used for transmitting over ranges up to 50 miles.

Valves in Parallel.—When two or more valves are connected in parallel the plate current curve is approximately the sum of their individual curves; on any applied voltage it is therefore much steeper than when one valve is used alone. On reaction between the plate and grid circuits the resulting induced potentials will cause greater amplitude of the oscillations set up in the plate circuit current, with a corresponding increase of oscillating energy in the aerial. Fig. 76 shows the non-oscillating curves.

Under transmitting conditions the result of connecting two receiver size French valves in parallel is shown in Fig. 136; the values were taken with 400 volts plate potential and 5 volts across the filament. With no external negative potential applied to the grid it will be seen that the aerial current for one valve is 105 milliamperes, but for two valves in parallel it is 170 milliamperes, the corresponding plate currents being 23 and 62·5 milliamperes respectively.

When a second valve is connected in parallel with the first the filament current is doubled and the ohmic drop of volts in the filament circuit consequently increased. If the series rheostat is not reduced to allow for this increased drop no advantage will ensue, as the oscillating current drops off rapidly with decrease of filament voltage.

The aerial current, and with it the transmitter output, can be further increased by connecting more valves in parallel, provided the wiring of the transmitter is large enough to carry the extra currents without undue ohmic losses. Or, what is

perhaps equally important, by using more valves in parallel the required output can be obtained with reduced filament and plate potentials, thus decreasing the strain on the valves, reducing insulation troubles, and simplifying the construction and upkeep of the H.T. battery or generator. The value of saturation current is proportional to the number of valves in parallel while the resistance of the oscillating plate circuit is inversely proportional to

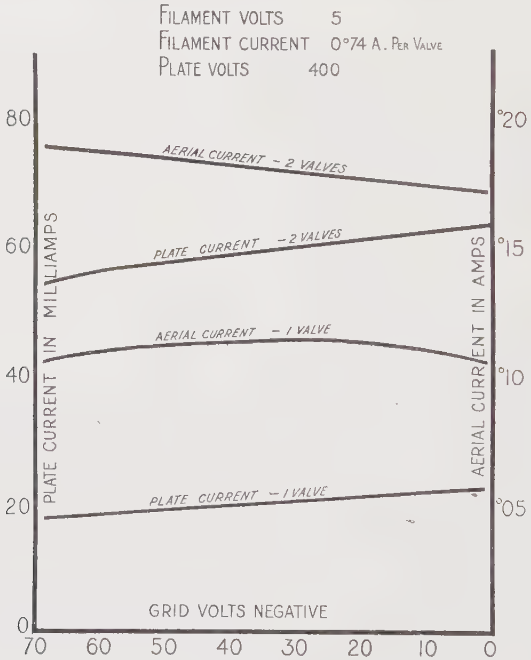


FIG. 136.

this number. Hence it can be deduced that the effective current oscillating in the plate circuit coil increases as the square root of the number of lamps.

Another method of increasing the power of the station is, of course, to use larger valves, specially designed for transmission work and for high voltages, such as the large Pliotron or Round valves already described. It follows from the characteristic curves of the valves that the radiated energy can be increased by increasing the filament temperature, or by increasing the H.T. voltage applied to the plate circuit, or both ; larger currents will then flow in the plate circuit and the valve design must be such

that it can deal with this increase of energy. The plate, filament, and grid must be larger and the vacuum more perfect.

There is, however, a limit to the size of a valve which can be constructed for efficient use. The construction of a large valve is not easy since the larger the electrodes the more difficult it is to create and hold a high vacuum in the valve, owing to the increased difficulty of pumping out the gases occluded in the glass and electrodes. Also at high voltages there are electrostatic attraction effects in the valve, which necessitate the use of wire struts for the grid and filament so as to preserve their positions relative to the plate; the introduction of these struts increases the vacuum difficulty besides adding to the expense of manufacture. The renewal of large valves is a costly item, for the life of a transmitter valve cannot be more than about 5000 hours of working.

At present (1922) the Marconi Co. are experimenting with the design of two large quartz valves which would deliver to the aerial 25 KWs. and 75 KWs. respectively. Yet present practice for large transmitters favours the employment of parallel banks of valves up to 4 KW. size; 50 or more of these can be used in parallel and with plate potentials up to 12,000 volts.

For small C.W. transmitters the high potential of the plate circuit can be provided by batteries; thus the British Military Service has used small dry cells made up in 200-volt battery units for this purpose. The life of dry cells is not very great under transmitting conditions, since the smallest station will use from 40 to 50 milliamperes in the plate circuit; the French Military Service employed secondary cells, but their weight is a serious drawback where portability is required.

For use with small stations motor-driven generators have now been designed to give the necessary plate voltage; these are generally made up complete with choke coils and smoothing condensers.

Another method sometimes used is that in which high voltage is obtained from a spark induction coil, and the current rectified by passing it through a rectifying valve. The current is then passed into a comparatively large condenser which acts as a reservoir of D.C. energy at the proper voltage; by the use of this condenser pulsations and inequalities are smoothed out. The terminals of the condenser are applied to the plate circuit as shown in Fig. 137.

This method was described by Dr. Langmuir in 1915 as having been used by him at that time; for larger stations an alternating current supply voltage can be stepped up through a transformer, which would therefore take the place of the spark induction coil

described above. These methods will be more fully described in the succeeding Chapter.

As regards rectifiers any valve with electrodes of unequal size can be used to rectify alternating current, since the flow of electrons across it can only take place in one direction, *i.e.* from the filament. Thus to use a French valve as a rectifier it is only necessary to heat up the filament in the ordinary way with a 4-volt battery, and then connect the plate and filament of the valve in series with

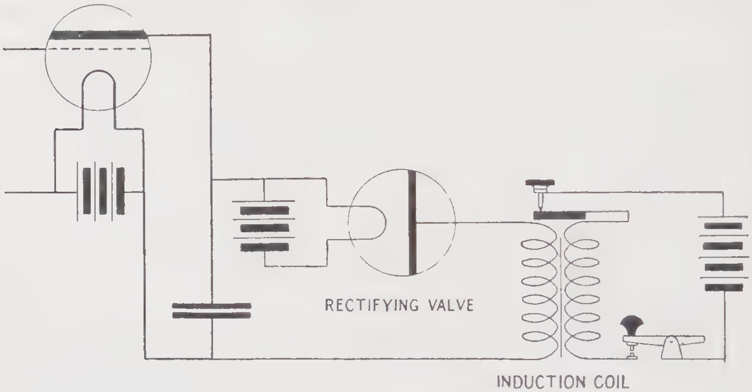


FIG. 137.

the alternating or pulsating voltage supply. The grid is not required and generally it is connected to the plate, thus helping to increase the surface of the anode, the filament forming the cathode.

Dr. Langmuir designed a rectifying valve which can be used for this purpose, and was called by him a "Kenotron"—it is illustrated in Fig. 138 and is suitable for use on voltages up to 50,000. Whilst any valve can be used for rectifying alternating voltages the efficiency can be increased by special design. The voltage in one direction should be entirely stopped by the rectifier, while that in the other direction should be delivered to the load terminals, and as little as possible of it absorbed in the valve itself as a drop of voltage between the anode and cathode. This means that the anode and cathode should be placed close together. Again, on high voltages, there is a great electrostatic attraction between the anode and cathode; it is necessary therefore to strut the filament cathode, and make the design such that these electrostatic forces are counter-balanced. An inspection of Fig. 138 will show how these points have been realised in the design of the Kenotron. Other designs of rectifying valves are shown in Chap. XVI.

The currents flowing through a hard vacuum valve rectifier are perfectly stable and several may be run in parallel to share the load ; in fact, it is better practice to do this than to increase the size of the rectifier.

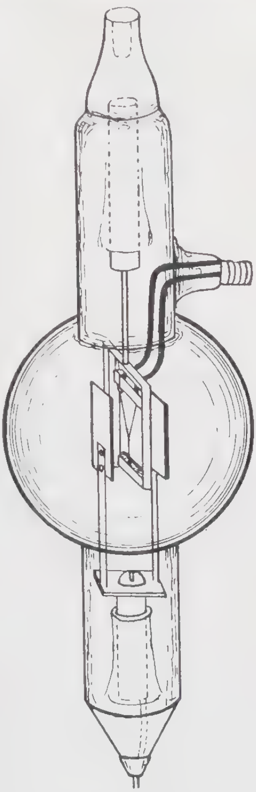


FIG. 138.

With a current of 50 milliamperes through a properly designed valve rectifier the voltage drop in it should not be more than 70 or 80 volts ; the remaining voltage, which may be several thousands, is available for consumption in the load, *i.e.* the transmitter valve circuit in series with the rectifier.

When a valve rectifier is used in conjunction with a spark induction coil, for obtaining high D.C. potential, the voltage induced in the secondary of the coil at " break " is very much higher than that obtained at " make " ; the connections must therefore be made so that the rectifier wipes out the smaller pulse of voltage and delivers the higher pulse to the transmitter valve. The simplest way to ensure this is to note the change in aerial current if the L.T. battery on the spark coil primary is reversed, and use that connection which gives the greatest aerial current.

When the source of H.T. volts for the plate circuit is an alternator, whose voltage is stepped up through a transformer, the amplitude of voltage rise is the same in both directions, so that the above-mentioned precaution in connecting up the rectifying valve is not necessary. It will be understood that with such an arrangement energy is only obtained from one-half of each cycle of the alternator, the other half being wiped out by the rectifying property of the valve.

This is a decided disadvantage, and to obviate it a method of using two valves has been adopted in which they are balanced on the secondary of the alternating transformer, as shown in Fig. 139. Here one valve draws its plate potential from one half cycle, the other valve functioning on the other half cycle. With this arrangement good sustained oscillations are obtained ; at the

same time a second winding on the transformer supplies current at low voltage to heat the filaments.

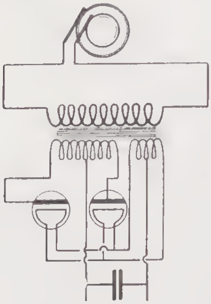


FIG. 139.

Under transmitting conditions it is not advisable to complete the plate circuit to one end of the filament, as this will cause unequal distribution of plate current along the filament. The plate current will be added to the filament-heating current in one half of the filament and opposed to it in the other half. With plate currents of 200 milliamps. or more the extra load on one half of the filament may shorten its life.

Therefore it is better to complete the plate circuit to the filament symmetrically by connecting it to the centre of the filament battery, or to the centre of the filament transformer winding where A.C. is used, as in Fig. 139.

Efficiency of Valve Transmission.—The efficiency of radiation will depend on the design and height of aerial; in our large commercial stations, by careful design, and avoidance of unnecessary resistance, from 40 to 50 % of the plate energy can be radiated.

QUESTIONS ON CHAPTER XII.

1. What are the advantages of C.W. transmission ?

2. Mention any important considerations which must be taken into account when designing a transmitter valve of large size ?

3. With two valves in parallel on a C.W. transmitter why is it that the aerial current is not generally double that given by one valve ?

4. What is the advantage of putting negative potential on the grid of a transmitter valve ? Is there any disadvantage ?

5. What are the considerations to be taken into account when designing a rectifying valve for use with alternating or pulsating current in a plate circuit ?

6. What are the functions of the condenser connected across the leads and the choke coils in series with the leads of a dynamo supply to the plate circuit of a valve ?

7. What are the oscillation frequencies in a C.W. transmitter when the transmission wave length is—

   (a) 1000 metres ?
   (b) 2500 metres ?
   (c) 6000 metres ?

8. Why is it possible to use comparatively short aerials on long wave length C.W. transmission ?

9. If the aerial and plate circuit currents in a valve transmitter are seen to be surging in value what is likely to be the fault ?

10. If no aerial current is being registered in a valve transmitter what faults would you look for ? How would you know if the valve circuits were oscillating ?

11. On a C.W. transmitter what is the effect of—

   (a) Increasing the aerial capacity,
   (b) Decreasing the aerial ohmic resistance,
   (c) Increasing the aerial radiation,

on the amplitude of the aerial current and its phase relationship to the plate potential ?

CHAPTER XIII

C.W. AND WIRELESS TELEPHONY TRANSMITTERS

Having dealt with some of the general features of C.W. transmission by means of valve oscillators, descriptions of a few actual transmitter circuits will now be given; from these it will be possible to arrive at some conclusions as regards the best methods to be adopted for any particular case.

Let us first consider the case of small transmitters; it has already been pointed out that a French type valve of receiver size, or even a Marconi Q valve, may be used in a transmitter for work over ranges up to 50 miles with aerials of moderate height. With 5 volts in the plate circuit of such a valve it is possible to obtain 100 to 200 milliamperes in a single wire aerial, without unduly loading the valve.

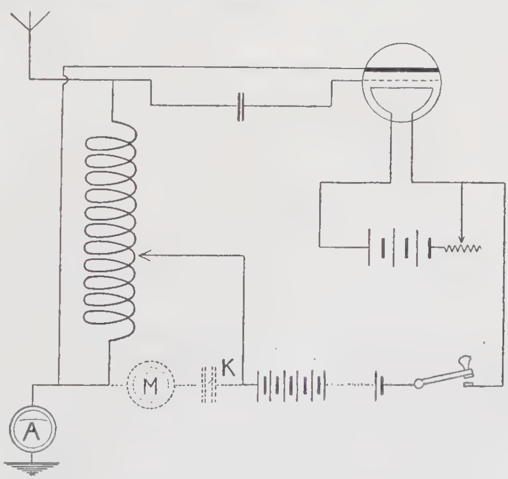


Fig. 140.

The simplest form of circuit for small transmitters would be that shown in Fig. 140; here the valve circuits are coupled in the manner already dealt with in Chap. V., Fig. 36, and the value of the coupling can be adjusted to give best results. One disadvantage of this circuit is that the wave length cannot be varied without varying the coupling; the transmitter may, however, be designed for one definite wave length or a small range of wave lengths may be obtained by

shunting a small variable condenser across the inductance coil. For maximum aerial current the aerial should have a definite capacity or size; this necessitates the use of a standard length and height of aerial for the wave length to which the transmitter is designed. With an ordinary French receiving valve on a transmitter of this description 150 milliamperes of aerial current were obtained on a wave length of 700 metres, the aerial being 20 yards long and 10 feet high.

If it is desired to use the apparatus as a transmitter for wireless telephony the key would be screwed down and a microphone, with condenser in series, connected as shown dotted at M and K. The range for wireless telephony would probably not be more than a third of the ordinary C.W. range.

A disadvantage of the connections shown in Fig. 140 is that if the H.T. battery in the plate circuit is badly insulated it will upset the aerial potential; in any case its capacity effect to earth may greatly influence the wave length, and may even stop the valve oscillating.

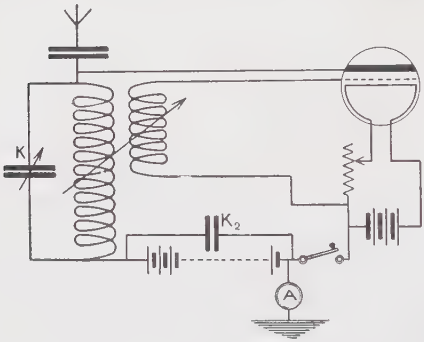


Fig. 141.

A better arrangement of circuit for a small transmitter is shown in Fig. 141; here the grid and plate circuits are coupled by independent coils, the wave length being adjustable by means of a small variable condenser K through a range which should not be more than an octave. Generally a blocking condenser of about 0·002 mfd. should be connected across the H.T. battery as at K_2; this will provide a low impedance path for the high frequency oscillating component of current if the battery is in bad condition or otherwise has a high resistance. The key breaks the plate current, and since it is connected to the earthed side of the circuit the operator is in no danger from shocks. The grid circuit is connected below the filament rheostat; this ensures that the grid is a little lower in potential than the lowest potential point of the filament. If necessary the transmitter may be designed with an extra loading or tuning coil in the aerial circuit, and the connection of the plate to the inductance in the aerial

made adjustable by a plug or multiple switch. A condenser of about 1 mfd. capacity is connected in series with the aerial so that undue potential strain is taken off the latter: without the condenser it would be at the full potential of the battery.

Another arrangement of a small C.W. transmitter is shown diagrammatically in Fig. 142; here the grid and plate circuits react on each other through loose-coupled coils, and the grid circuit can be tuned through a certain range of wave lengths by means of the condenser K. The plate circuit is tuned by means of the variable contact S, the aerial and earth acting as a loading

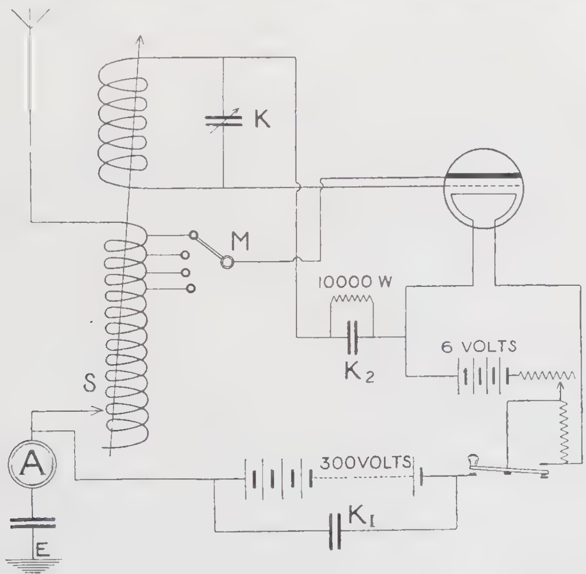


Fig. 142.

capacity on the plate circuit. Thus the grid and plate circuits can be roughly tuned to resonance, but it must be remembered that capacity effects decrease oscillations, and it will be found that with higher wave lengths, *i.e.* higher values of condenser K in the grid circuit, the oscillating component of the plate circuit current and the aerial current are reduced. As pointed out in Chap. V. the function of the grid circuit is to swing the plate current from zero to saturation; therefore all that is necessary in the grid circuit is a certain definite change of potential, brought about by inductance or capacity coupling. Nothing is to be gained

by a greater change of grid potential, and the necessary change can be obtained by a proper design of coils and coupling. A lowering of the saturation value of the plate current must be avoided. The variable condenser K would be better connected across the aerial inductance, if required at all for fineness of wave length adjustment.

It will be noted that the plate has an adjustable connection to the aerial tuning coil at the switch M; this enables it to be connected to the point on the coil which gives the maximum aerial current under any conditions of tuning, as explained in Chapter V. The best point will depend on the size of the aerial and on the wave length used; it regulates the ratio of the inductances in the plate and grid circuits to give best effects on the frequency or wave length chosen.

A condenser K_2, with 10,000 ohms leak across it, is connected in series in the grid circuit; this puts some negative potential on the grid and thus makes the valve function on a lower point of its curve than would otherwise be the case, reducing the plate current without reducing its oscillating component which is partially rectified. Finally, it will be seen that when the key is closed part of the filament rheostat is short-circuited by the back contacts on the key; the filament is only fully heated when the key is closed, and when the latter is open the filament current is reduced, thus taking the strain off the filament and reducing the current from the lighting battery.

A transmitter made on this principle had a range of wave length tuning from 700 to 1100 metres; using a small Marconi Q valve with 300 volts on the plate, and an aerial 100 feet long and 18 feet high, signals of strength R 9 were received from it on a good valve receiver over a range of 40 miles. The receiver aerial was about 60 feet high at the far end and sloping down to the receiver, which had a 3-valve L.F. Amplifier beyond it.

One of the earliest Transmission Sets was that made by the Marconi Company for use with Round transmitting valves of the soft vacuum type; although out of date it is interesting in some features. A diagram of this transmitter is shown in Fig. 143, and it will be seen that the key K is connected in the grid circuit. With a Round valve of the soft type the plate current is completely stopped when the grid circuit is left open, so that it is advantageous to control the current by putting the key in the low potential grid circuit rather than in the high potential circuit of the plate. With a hard valve of the Pliotron or French type

a current will flow in the plate circuit when the grid circuit is open, therefore to prevent waste of battery power the key should control the plate circuit. The adjustable resistance, with a maximum value of 10,000 ohms, is connected in the grid circuit to limit the flow of grid current and therefore of plate current. The grid cells bring the grid to a negative potential which, as previously explained, limits the plate current without reducing its oscillating component or the current oscillating in the aerial. The condenser across the grid battery and rheostat provides a low impedance path for grid circuit oscillating currents.

The radiated wave length is tuned roughly by tappings on

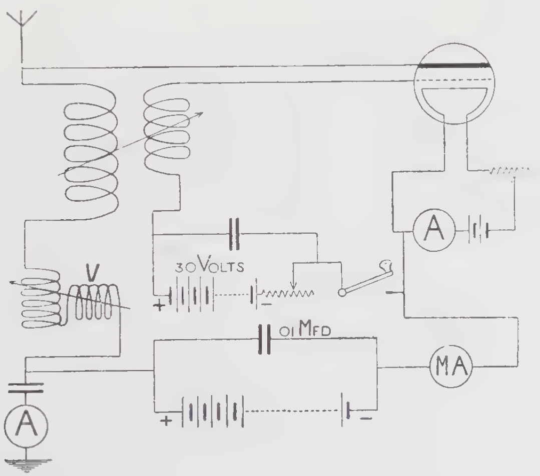


FIG. 143.

the plate circuit coil, and fineness of tuning is obtained by means of the variometer V. It will be noted that the aerial circuit condenser is in the earth lead so that the aerial is charged to the full positive potential of the plate, and the capacity effect of the battery to earth acts in the aerial circuit; this is not a good arrangement as the battery may interfere with the wave length.

In a paper read before the Institute of Radio Engineers in 1915 Dr. I. Langmuir described two arrangements employed by him as transmitters of wireless telephony; the methods can be adapted for C.W. transmission by small and obvious modifications.

In the first arrangement the source of H.T. volts is the local city supply of alternating current at 118 volts and 60 cycles

frequency; this is applied to the primary of a transformer on which there are two secondary, one of which supplies current at 5 volts to heat the filaments of the Pliotron valves employed, the other supplies current at 800 volts which is rectified by a Kenotron valve and charges a condenser of 6 microfarads capacity. The condenser, charged to 800 volts, is used as a store from which H.T. energy is drawn to the plate circuit of the main oscillating valve. The current drawn from the condenser does not vary the potential of the latter to any great extent during the interval between cycles of charge, so that the voltage remains practically

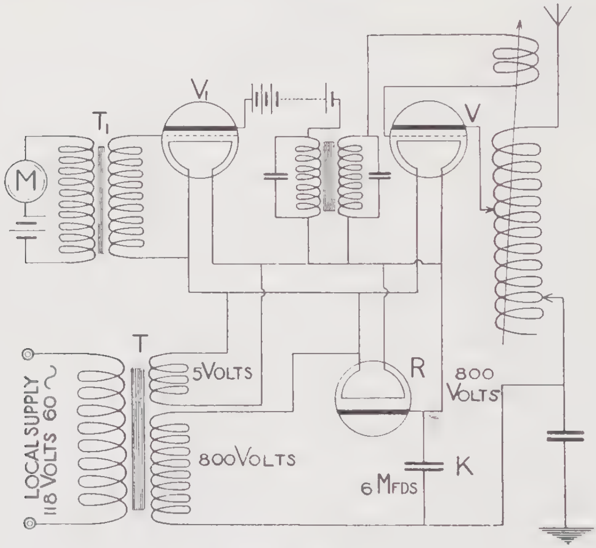


FIG. 144.

constant. The apparatus was designed to give about 20 watts in the aerial, and the microphone was connected to the grid circuit of an auxiliary valve, the plate circuit of which was coupled to the grid circuit of the main oscillating valve.

The connections, although not published, would appear to have been something as shown in the diagram of Fig. 144; V is the main oscillating valve and V_1 the control valve. The grid of the control valve is connected through a small transformer, T_1, to the microphone circuit. T is the main transformer, one secondary of which supplies current at 5 volts to heat the filaments of the two valves and that of the rectifying valve R. The other

secondary is connected through the rectifying valve to a condenser K from which H.T. energy at 800 volts is drawn for the plate circuit of the main valve V.

As long as the circuits are completed the main valve will generate oscillations and thus there will be undamped oscillations in the aerial: speaking into the microphone will cause pulsations of potential in the grid circuit of V_1; these are amplified through its plate circuit to the grid circuit of the main valve, thus setting up pulsations in the oscillations in the plate circuit of the latter. The aerial oscillations are therefore broken up into speech groups and the consequent radiation of energy will have the speech pulsations impressed on the waves. In the diagram of Fig. 144 it would be better to have reactance coils in the leads between the condenser K and the transformer, to prevent the high frequency oscillations in the plate circuit from getting back into the low frequency and supply circuits.

The second arrangement described by Dr. Langmuir was a 500 watt outfit. The source of H.T. supply was a small alternator of 2000 cycles frequency whose potential was transformed up to 5000 volts, rectified by Kenotron valves, and smoothed out by condensers; the high frequency making it possible to employ condensers of moderate size. The subsequent arrangement of the apparatus was similar to that described above for the smaller outfit.

The great advantage of this arrangement is that in the microphone circuit the amount of energy is no larger than that used in ordinary telephone lines, in fact a subscriber to an ordinary telephone exchange could be switched through to this apparatus if it were installed, and so speak by wireless telephony to places not connected by ordinary telephone lines. Thus long trunk lines for telephony may disappear.

The circuit can be used for ordinary C.W. transmission with a suitable keying arrangement in the grid circuit of the first valve; the A.C. supply may be replaced by a D.C. generator or battery, in which case the rectifying valve is not required. For small outfits the A.C. supply and transformer can be replaced by a spark induction coil with a battery of, say, 6 to 10 volts on its primary; in this case it is better to have a separate battery to heat the valve filaments.

An arrangement proposed by H. Round and experimented on by the author is shown in Fig. 145; the circuit is shown without tuning adjustments, but these can be provided by any of the usual

methods. Coil X in the aerial circuit was made of 40 turns of 94/40 S.W.G. rubber-covered cable, wound on a waxed-paper cylinder 7 ins. diameter and 6 ins. long, the inductance of the coil being 212,000 cms. The reactance coil Y consists of 50 turns of No. 28 S.W.G. copper wire wound on a waxed-paper cylinder $5\frac{1}{2}$ ins. diameter, the breadth of the winding being 1 in. and its inductance about 670,000 cms. This coil was placed at one end of X, and the coupling varied by moving it away from X or rotating it through an angle from 0° to 90°. As a matter of fact the inductance of the grid circuit coil Y was unnecessarily large, necessitating very loose coupling.

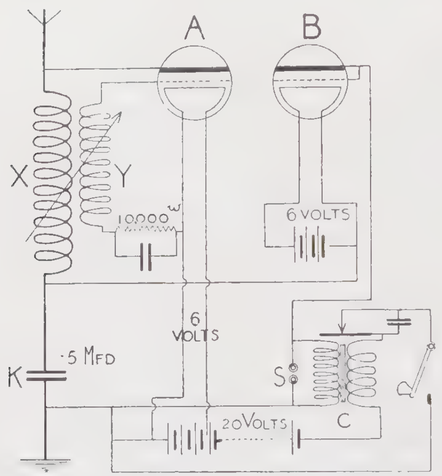


Fig. 145.

The valve A was a transmitting Round valve, as illustrated in Fig. 131, and had a resistance of 10,000 ohms in its grid circuit. The source of high potential was a 10-in. spark induction coil C with 20 volts on its primary; the voltage of its secondary was rectified in another Round valve B, and used to charge a $\frac{1}{2}$ mfd. condenser K, which was connected in series in the plate circuit of the transmitting valve A, and hence provided the necessary high potential. It was found that a capacity of $\frac{1}{2}$ mfd. was sufficient to smooth out all pulsations and give a pure C.W. note in the receiver. A safety gap S is connected across the spark coil secondary to guard the condenser K against excessive strains of voltage. The condenser must be carefully made, with best mica or glass dielectric, since the potential here employed is of the order of 6000 volts.

With this arrangement an oscillating current of 2 amperes was obtained in an ordinary aerial consisting of a single wire, about 40 yards long and an average of 40 ft. high.

Using a 1-in. spark induction coil as H.T. generator with 10 volts on the primary it was possible to get 0·7 ampere in the aerial. As thus described the wave length was 1500 metres; an

aerial tuning coil or variometer could be added for varying the wave length.

A development of this arrangement can be employed for wireless telephony transmission, as shown in Fig. 146.

The source of high tension is a spark coil S applied to the condenser K through a rectifying valve R; the valve V is employed to produce and keep up oscillations in the aerial, while the function of the valve V_1 is to produce telephonic pulsations in the aerial oscillations when the microphone M is spoken into.

As remarked before, the spark coil connections must be made so that the secondary current at break (not at make) of the inter-

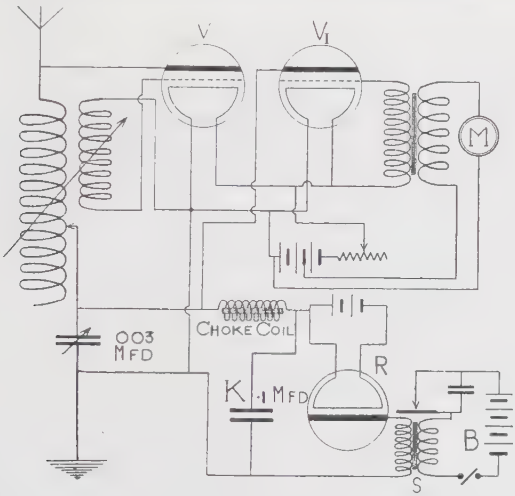


FIG. 146.

rupter passes through the rectifier. The choke coil prevents H.F. oscillations from getting back into the generating circuit; it also prevents high frequency harmonic pulses in the spark coil circuit from penetrating to the valve circuits.

A portable C.W. transmitter made by the Marconi Company had its circuits arranged as shown in Fig. 147; the valve fitted was a Round valve of the type shown in Fig. 131. The plate circuit is tuned to different wave lengths by means of a variometer, and the plate is maintained at a potential of 1000 volts positive by means of a small 1000 volts D.C. generator. The high tension supply is connected, through 2000 ohms, across a condenser of 0·25 mfd. capacity; this serves to smooth out inequalities of

voltage and is really the store from which energy is drawn for the plate circuit.

The arrangement of the grid circuit and key is interesting; when the key is open there is sufficient negative potential applied to the grid from the small battery B to prevent any current flowing in the plate circuit; when the key is closed the grid is made slightly positive with respect to the filament as it is now connected to the positive terminal of battery B, and through some of the cells and a leaky condenser to the negative leg of the filament. The aerial circuit is direct-coupled to the plate circuit and the presence of oscillating current in it can be detected by the lighting up of one of two lamps; the lamps have filaments of different resistances, and since the current in the aerial will depend on the length and height of the latter, *i.e.* on its capacity, the most suitable lamp can be chosen by means of switch S.

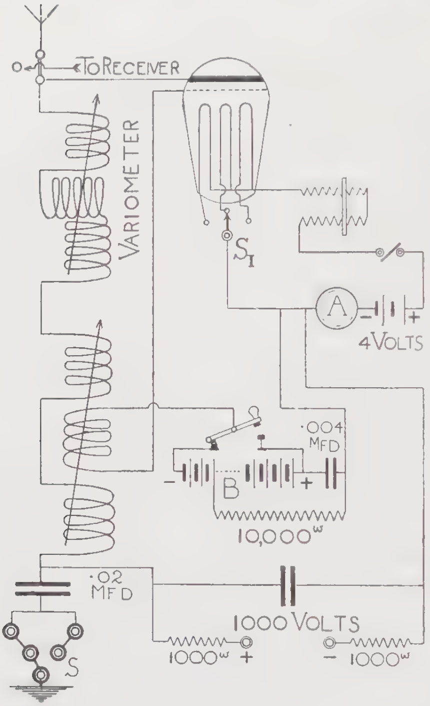


FIG. 147.

The Round valve has three filaments any one of which can be used, the selection being made by the switch S_1; in the actual transmitter this switch is of a cylindrical or drum design.

This transmitter is interesting not only because of the arrangement for manipulating the grid potential, making it possible to put the key in the grid circuit instead of in the high potential plate circuit, but also because tuning is carried out by a variometer instead of a variable condenser, which is always a source of weakness especially in a high potential circuit.

The little generator when developing 1000 volts delivered about 20 milliamperes to the plate circuit; this is a minor detail

as the arrangement can be employed with a greater amount of energy if necessary.

The receiver portion of this set is described in Chap. XIV. and shown diagrammatically in Fig. 161.

Fig. 148 shows a method by which the wireless staff of the French Military Service avoided any trouble from the capacity effect of the filament battery.

The plate and grid circuits are tapped off one coil ; the whole of this coil is included in the aerial circuit and enters into the calculation of wave length. The wave length can also be adjusted

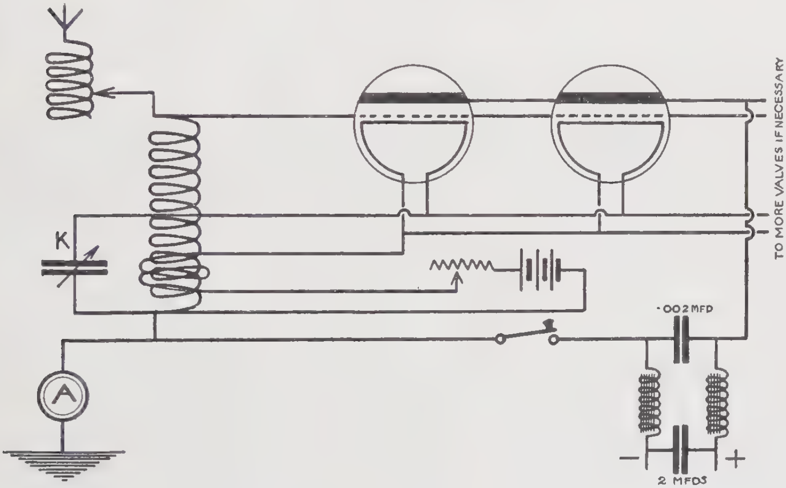


Fig. 148.

by an additional aerial tuning coil S and by a variable condenser K across the plate inductance.

The filament current passes through the plate circuit inductance and also through some turns of another coil wound over it ; by this means high frequency induction in the filament battery circuit can be neutralised. The key is on the earthed side of the H.T. supply, but the arrangement shown would be improved by having a condenser in series in the aerial circuit for reasons already stated in a previous paragraph. The plate and grid circuits are coupled by the capacity of the aerial as well as by inductance, thus size of aerial and change of wave length will, to some extent, vary the coupling. The possible capacity effects of the H.T.

unit and filament battery are small since they are both connected to earth.

A diagram of a high power transmitter employing large valves is shown in Fig. 149; for wireless telephony the system adopted is a development of that shown in Figs. 144 and 146. The reactance coils S_1 and S_2 stop the high frequency oscillations in the grid circuit from penetrating to the microphone amplifier circuit; the oscillations in the plate circuit cannot get back through the H.T. supply unit as they are stopped by the reactance coils S_3

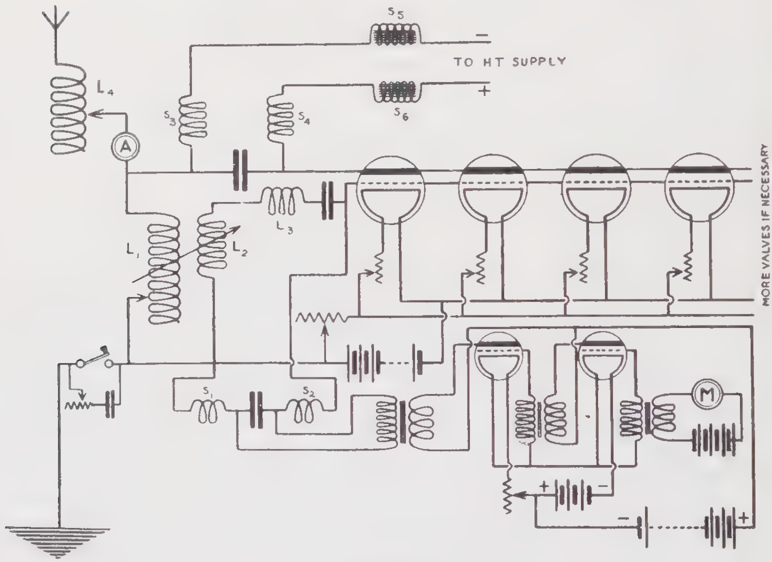


FIG. 149.

and S_4. The choke coils S_5 and S_6 stop low frequency pulses in the H.T. unit (which may be caused by commutator ripples on a dynamo) from penetrating to the oscillating circuits, this effect being aided by the condenser shunted across S_3 and S_4. The microphone pulses are amplified first in the two cascade valves and then introduced into the grid circuit of the power valves at the condenser between the choke coils S_1 and S_2.

The condenser in series with L_3 allows the high frequency induction to affect the grid potential but prevents the low frequency pulses from expending themselves in the grid circuit coils. It is seen that though the transmitter may be a high power one the micro-

phone is in an ordinary low potential circuit. For C.W. transmission a key is employed in the aerial circuit ; since the currents are heavy the key is shunted by a condenser and rheostat in series. Other arrangements of key, such as relay keys, suggest themselves.

For wireless telephony the key is screwed down, and the amplified pulses of microphone current vary the potential of the grid, therefore change the plate current. A change of plate current changes the potential of the plate, since this equals $V - L\frac{dc_p}{dt}$, where V is the applied voltage, L the inductance in the plate circuit, and C_p the plate circuit current.

A change of plate potential will have a comparatively great effect on the aerial current, so that the microphone pulses are well impressed on the oscillations in the aerial.

It may be recalled that reception of C.W. signals can best take place when locally generated oscillations of weak amplitude act in the receiver circuits ; these form beats with the undamped oscillations set up in the receiver by the signals from the transmitter. The simplest method of reception is to employ on the receiver a valve detector with a reaction coupling between its plate and grid circuits strong enough to make the valve generate oscillations, which will form beats with the induced oscillations by slight mistuning. Unfortunately a valve receiver with such reaction adjustment will not only amplify but also heterodyne spark signals which will lead to considerable trouble from jamming ; if the reaction coupling is decreased the valve will have ceased to generate oscillations, or to receive C.W. signals, before the spark signals are sensibly reduced in strength. In any case the necessary mistuning lowers the sensitivity as explained in a previous Chapter.

In order, therefore, that crystal detectors may be employed for C.W. reception, or loosely coupled, sharply tuned, receiver circuits which will cut out spark signals, a separate heterodyning arrangement is often preferred. Where the transmitter is a relatively small one, employing the receiver size of valves for generating oscillations, it might be convenient to use one of these for the local heterodyne when reception is taking place. A transmitter designed with this end in view was used by the French Military Service, and a diagram of its connections for transmission is given in Fig. 150. It will be seen that four valves in parallel are employed with a coil P in the plate circuit and a coil G in the grid circuit ; the plate and grid circuits being coupled by means

of the variable condenser C. This method of coupling has been dealt with in Chap. V.

It will be noted that the plate circuit potential is only 320 volts; this is because the Set was designed for portability and ordinary field service ranges. The plate potential may be obtained from a battery, from a spark coil and rectifying valve, or from a D.C. generator driven by a small petrol engine or a motor which may receive its motive power from, say, a 20-volt battery. The condenser C_1, shunted across the H.T. supply, has the usual

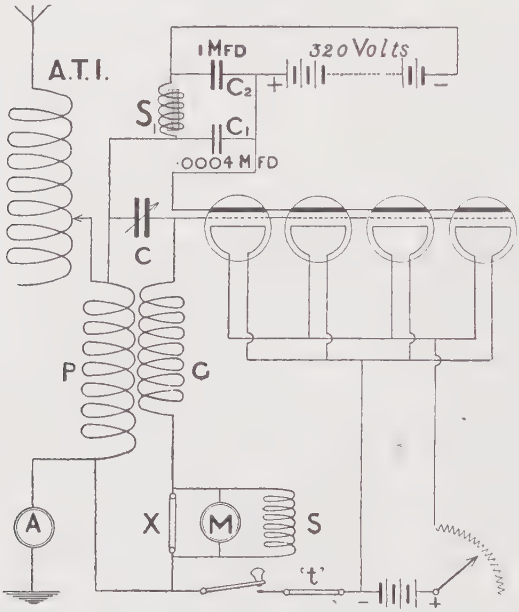


FIG. 150.

function of providing a low impedance path for the plate circuit oscillations; the condenser C_2, of 1 mfd. capacity, smooths out irregularities in the supplied voltage, especially those due to commutation if a generator is employed, while the choke coil S_1 serves to prevent the high frequency commutator pulses from going to the valve circuits.

There is a link X in the grid circuit shunted by a coil S, of small inductance; ordinarily the link is in position, but if it is desired to use the Set for wireless telephony transmission the

link is opened and a microphone M is connected across the terminals, the key contact being screwed down.

In series with the key is a link, l; if desired this link may be taken out and a tikker connected across the terminals, so that transmission can be made on a musical note and, if necessary, reception on a crystal detector. The tikker may consist of a toothed wheel driven by a rubber belt from the motor generator and rotating under a small brush, the wheel and brush being connected respectively to the terminals; by using wheels of different diameters the note can be varied.

The aerial circuit has a tuning inductance and is connected to the plate circuit of the valves; with a 6-volt filament battery and 320 volts in the plate circuit the aerial current can be 0·5 ampere on a 1000-metre wave length or 0·75 ampere on a 560-metre wave length. Ordinary French valves of receiver size are used and a V-shaped aerial, each leg of the V being 50 metres long and 7 metres high with a total aerial capacity of 0·0004 mfd. The valve circuits were designed for a wave length of 560 metres and the aerial tuning inductance permits of this being increased to 1000 metres.

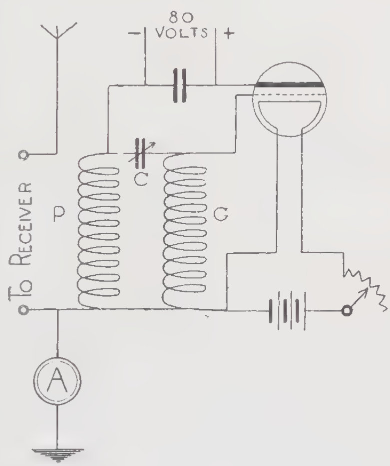


Fig. 151.

On reception one of the valves is turned into a heterodyning valve by means of a change-over switch; this disconnects the aerial and the other three valves, shorts the key, puts 80 volts instead of 320 on the plate circuit of the remaining valve, and inserts more resistance in its filaments circuit. The consequent connections of the heterodyning valve are shown in Fig. 151; since the circuits have been used to transmit on a certain wave length the valve is almost correctly adjusted to heterodyne signals on the same wave length when the switch is turned to "Receive," but the fact that the aerial and the other three valves have been switched off makes a slight readjustment necessary on the condenser C.

Where large valve transmitters are employed, with a number of generating valves in parallel, the signals can be made by

modulating the grid potentials of these valves through a smaller controlling valve or valves in cascade. It is probable, however, that high frequency generating machines will be employed for C.W. transmitters of higher rating than 100 kilowatts. At the present time these machines are being satisfactorily developed, and they will probably prove to be less costly in upkeep than valve generators. A description of high-frequency machine design and circuits will be found in Chap. XV. together with some further valve oscillator connections suitable for C.W. or radio-telephony transmission.

Fig. 152 shows a $\frac{1}{2}$ KW. Transmitting valve made by the G. E. Co., at their Hammersmith works, while Fig. 153 is a view of one of the later types of Marconi 3 KW. Valve Transmitter Panel.

A more recent design of Marconi Transmitter is described in Chap. XVI., and it may be noted that this Company at its Clifden and other stations employed banks of valves each delivering up to 4 KWs. of energy to the aerial, with a total aerial energy up to 100 KWs.

Manipulating Key and its Position in the Circuit.—Any of the usual designs of key may be employed, but if it is connected in the aerial circuit it should be shunted by a spark dissipating circuit for small stations, and for large stations it should actuate a special relay key. If connected in the aerial circuit, the valves will be using energy whether the key is open or closed. If it is connected into the filament-heating circuit the valve or valves may not start oscillating. If it is connected into the grid circuit, where the current is comparatively small, current will still flow in the plate circuit when the key is open, unless by opening the key a negative potential is put on the grid sufficient to stop the plate current. For small transmitters the key should be in the plate circuit, which can be arranged so that the key is earthed and thus will not give shocks to the operator. The circuits can be so arranged that the key opens both plate and grid circuits simultaneously as in Fig. 150.

On large stations it is not practicable to put the key in the circuit of the H.T. supply generator as this may introduce lag effects. In small transmitters, where the H.T. supply is taken through a rectifying valve from a spark coil, the key may be placed in the circuit of the battery which excites the coil, but again owing to lag effects at the vibrator this will limit the speed of signalling, otherwise dots will be clipped or missed altogether. To overcome this as much as possible the vibrator should be

comparatively stiff, with a high natural frequency of vibration.

FIG. 152.—$\frac{1}{2}$ KW. Transmitting Valve made by the G. E. Co., London.

It is not a very satisfactory arrangement to have the key directly in the grid circuit; the author has had experience of a C.W. transmitter where the key was shunted across a leaky condenser in the grid circuit and it was found that much trouble was caused by faulty insulation, moisture, dust, etc., on the key.

H.T. Supply for Plate Circuit.—The high voltage required for the plate circuit may be supplied by primary cells for small and portable stations, but where weight is not a material point it is better to use small secondary batteries. These may be charged in parallel groups off 100-volt lighting mains and used in series on the plate circuit of the valve. A small transmitter fitted with one receiver-size valve will not take more than 0·05 ampere (50 milliamperes) in the plate circuit, therefore quite small secondary cells will be suitable for the purpose.

Instead of using a high voltage battery a low voltage one of 10 or 12 volts may be used, in combination with a spark induction coil and valve rectifier as already described. With larger transmitters and larger valves it is usual to employ high voltage D.C. generators, or A.C. supply stepped up through a transformer, rectified by a valve rectifier, and smoothed out in a condenser.

It is important that the capacity effect to earth of the H.T. battery or unit should not influence the wave length by acting in shunt with the plate circuit coil; this can be best assured by arranging the transmitter circuit so that the negative terminal of the battery is connected to earth as shown in most of the preceding diagrams.

Aerials for C.W. Work.—A single wire aerial 100 to 125 ft. long and supported on masts 25 ft. high will be suitable for ranges up to 50 miles, on wave lengths up to 1000 metres, and transmitters of 50 watts energy. It would be better to have a two-wire aerial which will have a capacity of 0·0003 mfd. and a natural wave length of about 330 metres.

For ranges up to 200 miles the aerials should consist of two stranded wires 10 feet apart and supported on 70-ft. masts. The transmitter energy required for this range will be about 120 watts, though of course no hard and fast rule can be laid down as it depends on the efficiency of the transmitter and the amplification at the receiver.

For C.W. transmission it is advisable to have a condenser of fairly large capacity in the aerial circuit, as shown in some of the preceding diagrams. If the condenser is connected between the aerial coupling coil and the aerial, or aerial tuning coil, it prevents

the aerial from being subjected to high potential strains, and does not greatly change the capacity effect of the aerial as a whole. Thus if the aerial circuit without the condenser has a capacity of

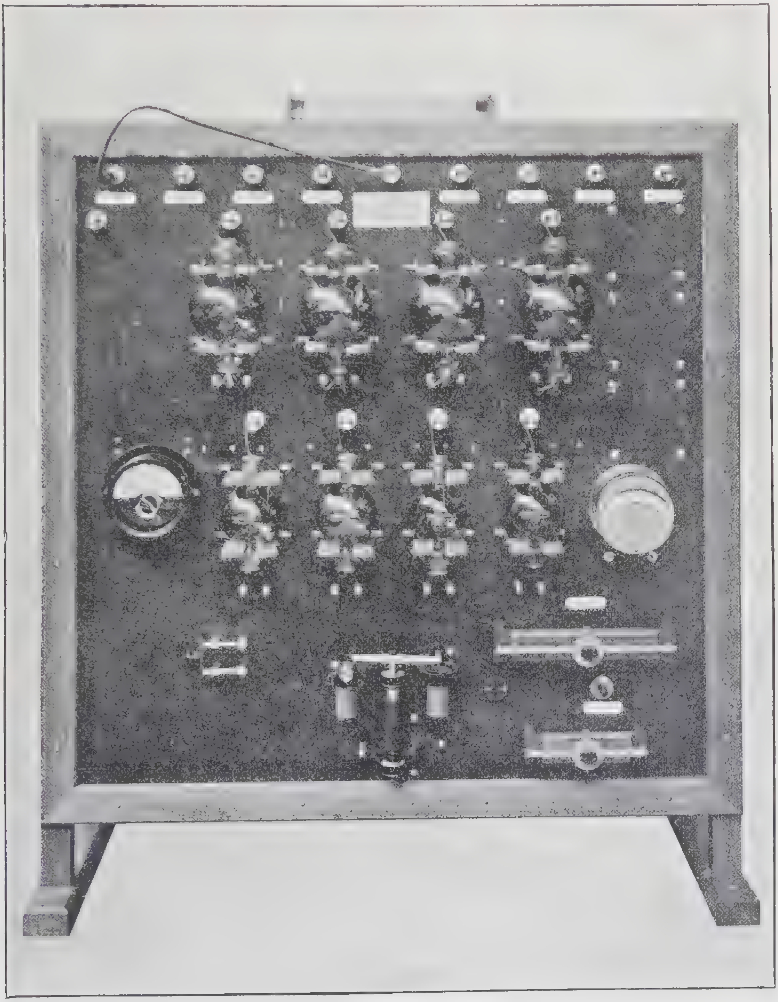


FIG. 153.—Marconi 3 KW. Valve Transmitter Panel.

0·0005 mfd. the addition of 1 mfd. in series only changes it to $\frac{0{\cdot}0005 \times 1}{1 + 0{\cdot}0005}$ or 0·0004997 mfd. The condenser also saves the

valves and H.T. unit from being overrun if the aerial is damaged or otherwise earthed. If the condenser is put in the earth lead, as shown in some of the preceding diagrams of transmitters, it ensures that the plate circuit is insulated from earth.

A two-wire aerial 300 ft. long and 48 ft. high will have a capacity of about 0·001 mfd. and a 150-watt C.W. transmitter can put about 1 ampere of current in it. If the aerial consists of 10 wires and has a capacity of 0·0035 mfd. the aerial current should be about 2·5 amperes on a 150-watt valve transmitter.

The condenser should be shunted by a safety spark gap to prevent the aerial from being dangerously charged by atmospheric storms. On wireless telephony transmitters it is not so feasible to have a series condenser in the aerial circuit ; its impedance to the low frequency pulses impressed on the oscillations by the speaking circuit may be high unless its capacity is kept small, and this is not feasible in large transmitters.

QUESTIONS ON CHAPTER XIII.

1. What points should be considered as regards the position of the manipulating key in a valve transmitter circuit ?

2. Draw a diagram of suitable arrangements for obtaining a high potential on the plate circuit of a large valve transmitter.

3. What are the considerations which must be taken into account when choosing the design and size of an aerial for C.W. working ?

4. In a valve transmitter what happens if—
   - (*a*) The filament voltage is too low ?
   - (*b*) The plate voltage is too low ?
   - (*c*) The leads to the shunt condenser across the source of plate potential are broken ?
   - (*d*) The insulation of the aerial is defective ?
   - (*e*) The resistance of the earthing is too high ?

5. The reactance coupling between the plate and grid circuits of a valve transmitter is so loose that the valve is not oscillating. If the coupling is now tightened to a certain value the current reading on the plate circuit ammeter changes in value. Why is this ?

6. If you gradually increase the capacity across the plate circuit of an oscillating valve the plate current rises at first but beyond a certain capacity value it falls again. Explain this result.

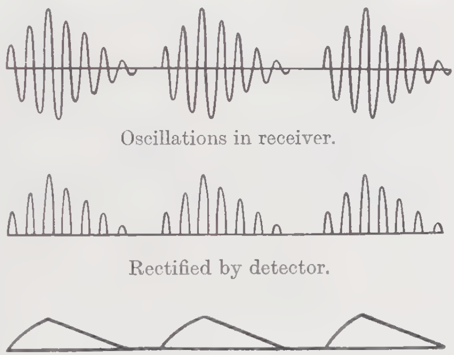
7. In a valve transmitter a battery was employed to put negative potential on the grid. The grid was connected to the negative terminal of the battery, but the grid circuit was not completed at the positive terminal. Under these conditions the valve was found to generate oscillations and give a current in the aerial. Explain this result.

8. How would you make up a valve circuit to radiate very long waves approaching audible frequency ?

CHAPTER XIV

C.W. AND RADIO-TELEPHONY RECEPTION

When the key of a spark transmitter is pressed to make a signal several sparks take place: each gives a train of ether waves, and each train of waves induces a group of small oscillations of current in the receiver circuit: the oscillating potentials resulting therefrom are applied across the detector and telephones and one pulsation of the telephone diaphragms takes place at each train. This is diagrammatically shown in Fig. 154.

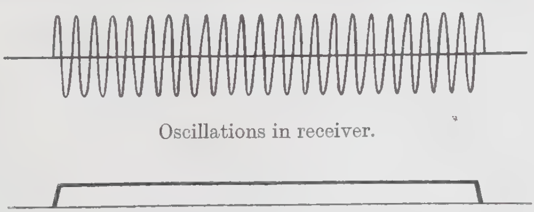


Oscillations in receiver.

Rectified by detector.

Fig. 154.—Telephone pulses.

If the oscillations and resulting ether waves are undamped, as in C.W. work, small undamped oscillations are induced in the receiver circuit, rectified by the detector, and smoothed out owing to the high impedance of the detector and telephones, as shown in Fig. 155. It will be



Oscillations in receiver.

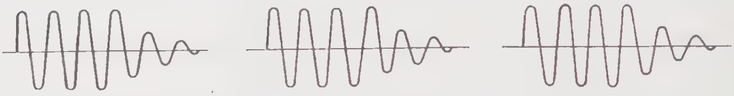
Fig. 155.—Telephone current.

seen that when the transmitting key is closed a pulse of current starts in the telephone receivers, which may cause the diaphragms to click but they will remain steady until the opening of the key;

the diaphragms will not vibrate and thus no note will be heard except the clicks at the opening and closing of the keys; these clicks will only be heard on short ranges.

Thus C.W. signals cannot be received on a simple rectifying arrangement, such as a crystal detector, unless something is done to break up the pulse of telephone current resulting from each signal so as to cause vibrations of the telephone diaphragms. Before considering the usual method of receiving signals from valve transmitters by employing local oscillations which heterodyne the received oscillations, as explained in Chap. VIII. and illustrated in Fig. 66, let us first briefly consider other methods which have been or can be employed.

In the description of a 4-valve French transmitter given in Chap. XIII. and illustrated in Figs. 150 and 151, it was explained



Oscillations in receiver.

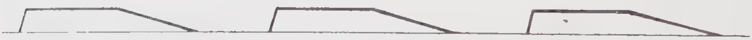


FIG. 156.—Telephone pulses.

that a tikker could be connected into the transmitter valve circuits so that it would break up the oscillations into groups, the frequency of these groups depending on the rate of interruption caused by the tikker. This will give an effect at the receiver differing only from that of spark signalling in the fact that the energy pulses from the ether waves are undamped, so that the receiver oscillations only begin to damp out when the group of ether waves ceases.

It will be seen that the resulting effects in the receiver are as shown in Fig. 156; an ordinary crystal detector may be used and the telephone diaphragms will vibrate, giving a note corresponding to the frequency of interruptions due to the tikker in the transmitter circuit. Where a valve transmitter is employed the tikker may be connected into the plate circuit or the grid circuit; the latter is preferable since the grid currents are small.

The same result can be obtained by using a make and break in the aerial transmitting circuit; this may be a rotary one driven at a speed which will give interruptions at a musical frequency, or it may be a buzzer arrangement, in which case the transmitting key may be in the buzzer circuit. For wireless telephony a microphone connected through a step-up transformer into the grid circuit or into the aerial circuit will give similar results; in this case the pulses of energy radiated as ether waves will not be uniform but will be modulated by the speech currents in the microphone circuit.

Another method is that of using alternating or intermittent potential on the plate circuit of the transmitting valve or valves. Thus if the H.T. voltage is obtained from a spark induction coil, without a rectifier, condenser, and choke coils to smooth out the potential variations, the signals in the receiver will have the note of the spark induction coil with the sharp tuning effects of continuous wave transmission. In the latter case the transmitting key would be in the primary circuit of the spark coil.

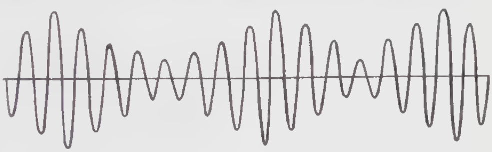


FIG. 157.

Again an auxiliary valve may be employed whose circuits are so designed that it generates oscillations at a musical frequency; these oscillations could then be introduced into the grid circuit of the generating valve. The amplitude of the resulting oscillations in the transmitter tuned circuits would rise and fall as shown in Fig. 157, at a frequency determined by the note of the auxiliary valve. For a small transmitter a method of connecting the auxiliary valve circuit to the generating valve circuit is shown in Fig. 158; here valve V_1 is setting up high frequency oscillations in the aerial circuit, whilst low frequency oscillations are generated in the plate circuit of valve V_2 by reason of the fact that it contains a large value of inductance, being coupled to the grid circuit by means of an iron-core telephone transformer T_1. This musical note of V_2 can be tuned by varying the inductance or by a variable condenser as shown. The low frequency oscillations of V_2 are introduced into the grid circuit of V_1 through the small iron core transformer T_2 with high resistance windings on both primary and secondary; thus the low frequency oscillations are superimposed on the high frequency oscillations

generated in V_1. The transmitting key is not shown in the Figure: it can be conveniently connected in the positive lead from the battery to the plate circuit of V_2.

Although all the methods just described will give signals which require sharper tuning at the receiver than ordinary spark signals, they do not provide continuous wave transmission; when received with crystal detectors the range will not be much greater than with spark transmission, but they have the advantage of a tuned note by which the transmitting station may be identified.

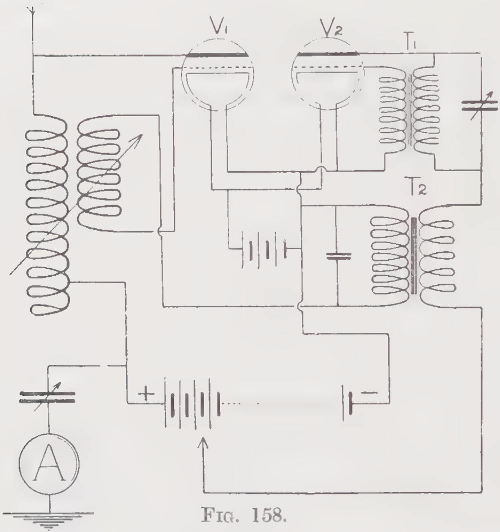


FIG. 158.

Instead of causing pulses, or groups, in the transmitter oscillations the valve transmitter may be employed in the ordinary way to give continuous waves, and the resulting undamped oscillations in the receiver circuit may be broken up into groups by using a small tikker arrangement in the receiver. This was the original method employed on the Poulsen System, which employed an arc generator of undamped oscillations at the transmitter. With such a method the sharp tuning effect of undamped radiation is obtained, also the ranges will be greater for a given primary energy than with spark signalling, but they will not be as great as when beat reception is employed, for reasons which have been already explained in Chap. VIII.

If the local oscillations at the receiver with beat reception are supplied from a source quite independent of the receiver circuit and detector the latter may be a crystal combination; it is, however, more usual to employ a valve rectifier so as to get the advantage of reaction amplification. Modern receivers consist of two or more valves in cascade to provide limiting, amplifying, or selective properties.

For C.W. signals a heterodyne receiver circuit will have to be very sharply tuned on short waves; signals on short waves may be lost if the variable tuning condenser is moved through one or two scale divisions, but long wave signals may be heard over a long range of the condenser. A little consideration will make this clear. Suppose signals on 600 metres wave length are to be received; their oscillation frequency is 500,000 per second and to form a beat frequency of 1000 per second the local circuit must be tuned to a frequency of 499,000 or 501,000 per second, that is to say to approximate wave lengths of 601 or 599 metres respectively. Thus beats of this frequency allow of a tuning range of only two metres. If, however, the received wave length is 6000 metres, corresponding to a frequency of 50,000 per second, the same beat frequency will be obtained by tuning the receiver circuit to 49,000 or 51,000 frequency, corresponding to wave lengths of 6123 and 5882 metres respectively. In the first case there will be a silent point when the receiver is tuned to 600 metres and the beat will have reached a frequency of 1000 with mistuning of 1 metre either side; in the second case there will be a silent point when tuned to 6000 metres and the beat will not have reached a frequency of 1000 until mistuning of 120 metres either side has been made, while notes of lower frequency will be heard over a considerable part of this range. If the same variable condenser is employed for tuning in both cases it will be seen that it must be sharply adjusted for the short wave, but signals will be heard over a considerable part of its scale on the long wave.

Incidentally it is also apparent that, for tuning in C.W. signals on wave lengths of 1000 metres or less the variable condenser should have a small maximum value, so that a variation of 1 or 2 metres wave length corresponds to a range of several divisions on the scale of the condenser.

The simplest circuit for C.W. reception, using a French valve, is one already described and shown again in Fig. 159. With sufficiently close reaction between the plate and grid circuits the valve generates oscillations, and, by slight mistuning of the grid circuit, these can be made to form beats in the aerial tuning inductance with the oscillations set up by the ether waves; at the same time amplification effects are obtained through the reaction. The variable condenser K connected across the grid circuit for tuning purposes must be of small maximum capacity (say, 0·0005 mfd.). It will be noted that the plate circuit is not tuned, *i.e.*

is aperiodic. An advantage would be gained by tuning the plate circuit but instead of complicating this simple circuit by connecting a variable condenser across the reactance coil it would be better to adopt another form of circuit such as will be presently described.

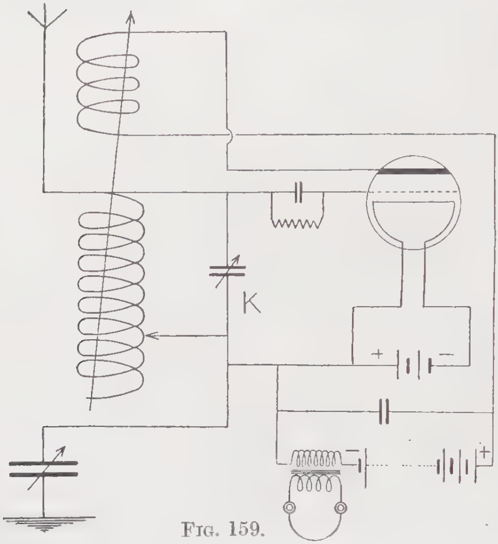


Fig. 159.

The grid circuit may be made aperiodic, and the tuned aerial inductance included in the plate circuit as shown in Fig. 160; here the oscillations in the aerial circuit by transformer action produce oscillating potentials in the reaction coil, therefore in the grid circuit. These produce oscillations in the plate circuit which includes the aerial tuning inductance, therefore the aerial oscillations are amplified. By sufficient reaction coupling and slight mistuning oscillations are generated in the valve circuits which form beats with those set up by the ether waves, and signals thus received. Instead of making the grid circuit aperiodic it might be tuned by connecting a variable condenser of small maximum capacity across the reaction coil;

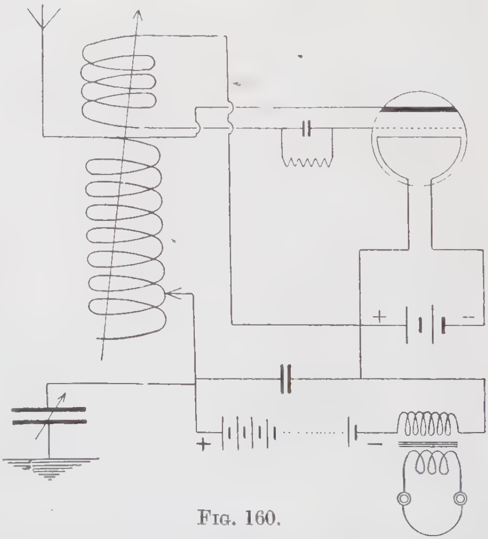


Fig. 160.

not much advantage would be gained by this on weak signals, for any benefit gained by having a tuned grid circuit is discounted by the fact that a condenser connected across the circuit tends to keep down the oscillations of potential of the grid.

The connections of a small portable receiver made by the Marconi Company are shown in Fig. 161; the receiver circuit is

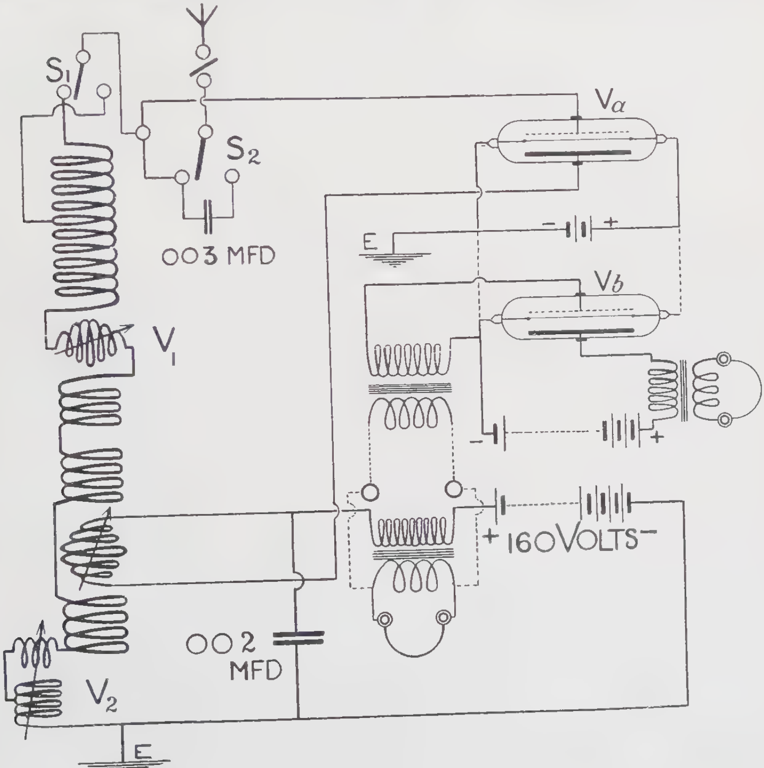


Fig. 161.

tuned by a coarse variometer, V_1, and a fine one, V_2, so that the use of a variable condenser is avoided. Switch S_1 changes the amount of inductance in the aerial circuit, also by means of switch S_2 a condenser of 0·003 mfd. can be connected in series in the aerial; thus a good range of wave lengths is obtainable on aerials of different lengths. The receiver is fitted with a small Q type valve V_a, and if necessary a second valve V_b can be connected up to give L.F. amplification. The connections of the valve circuit

V_b to the main circuit are shown dotted in the Figure. It is seen that no attempt is made to bring the grid of the valve V_a initially to negative potential; this is because negative grid potential is not necessary with Q valves, as already explained in Chap. X.

It must be remembered that the use of a leaky grid condenser is only applicable with a French valve, or those having similar characteristics. In all other cases the proper grid potential to work the valve at its most sensitive point for rectification is best obtained by means of a potentiometer. Where a potentiometer is employed it is preferable to connect it to the filament and not in the grid side of the grid circuit; this arrangement is shown in Fig. 162.

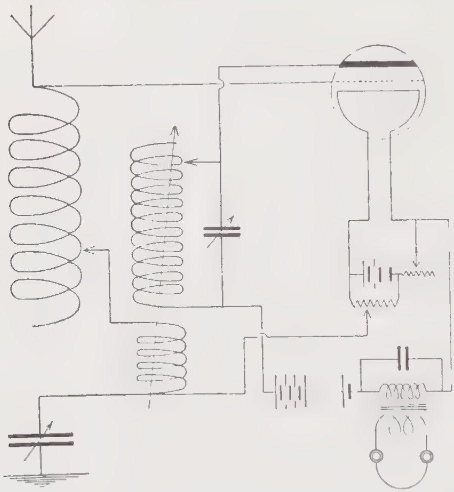


FIG. 162.

The connections in Figs. 159 and 160 have the disadvantage that the C.W. signals are liable to be badly jammed by spark signals, not necessarily in tune. A pendulum will oscillate with maximum amplitude if the pulses of energy applied to it are in tune with its natural frequency of vibration; if, however, the pulses applied are erratic, or out of tune, the pendulum will still be disturbed and some amplitude of oscillation set up. Similarly an aerial circuit may not be tuned to ether wave pulses yet the latter will set up oscillating currents in it, feeble no doubt, yet if amplified by a reacting valve they may become strong enough to give signals. Thus high-power, or local, spark stations will set up oscillations in either of the aerial circuits of Figs. 159 and 160 even though it is not tuned to the spark wave length; these oscillations are amplified by the valve through the reaction coil and, since the valve is oscillating, they are heterodyned; the resulting hoarse note of the spark signals may interfere seriously with the reception of weak C.W. signals.

For this reason it is preferable to employ loosely coupled

tuned circuits in the receiver as shown in Fig. 162 ; here the aerial inductance is included in the grid circuit, with a potentiometer between the grid and the filament to make the valve function on the best point of its characteristic curve. The grid should be at such a potential that the grid current is zero or very small, the grid circuit resistance is then very high and it does not damp out the oscillations in the aerial circuit ; also the valve will rectify the high frequency oscillations in the beats.

The plate circuit is tuned, and the coupling between it and the grid circuit should be just strong enough to make the valve generate oscillations. Sometimes the condenser which provides a path for the plate circuit oscillations is not connected across both the H.T. battery and the telephone transformer primary, but only across the latter as shown in the Figure ; this is because the resistance of a 25-60 volts H.T. battery is small compared with the high impedance of the transformer winding.

The variable condenser across the plate circuit should have a range only sufficient to give accurate adjustment of wave length between the studs of the variable inductance ; the tuning should be adjusted with as high a value of inductance and as small a capacity as possible.

There are now two circuits to tune, and if it is desired to pick up a station the best procedure is as follows :—Short-circuit the aerial tuning condenser at 180°, or leave it at a fairly high value, and set the aerial tuning inductance at some value roughly corresponding to the wave length of the transmitting station ; set the coupling fairly tight. Now search for the signals on the closed circuit, swinging the closed circuit condenser as the inductance switch is moved from stud to stud. On picking up the signals tune them in on the highest possible value of inductance and smallest value of capacity. Now tune in, first the aerial inductance, then the aerial condenser, and adjust the coupling for best signals. If necessary the coupling can be made loose in order to cut out spark signals.

If it is desired to amplify the note with a second valve, without using a Low Frequency Amplifier external to the receiver, a good circuit connection could be made up as shown in Fig. 163 ; here the tuned circuit of the first valve is loosely coupled to the aerial circuit, and the second valve acts as a L.F. Amplifier or note magnifier. Since the first valve is required to generate oscillations a small condenser K is connected across the high impedance portion of its plate circuit. The variable tuning condenser may have a

maximum capacity of 0·0004 to 0·001 mfd. As has been frequently pointed out it is inadvisable to increase the wave length range of a valve receiver by tuning with appreciable capacity in either the plate or grid circuits; variable condensers can be replaced by a variometer to give fine tuning of inductance, and this use of variometers is likely to be standard commercial practice in the future. The fine tuning of inductance may be effected by a variometer of the usual coil type, connected in series with the main inductance coil, or by small rings of iron which can be displaced relatively to the axis of the inductance coil. The use of such rings would vary the self capacity as well as the inductance

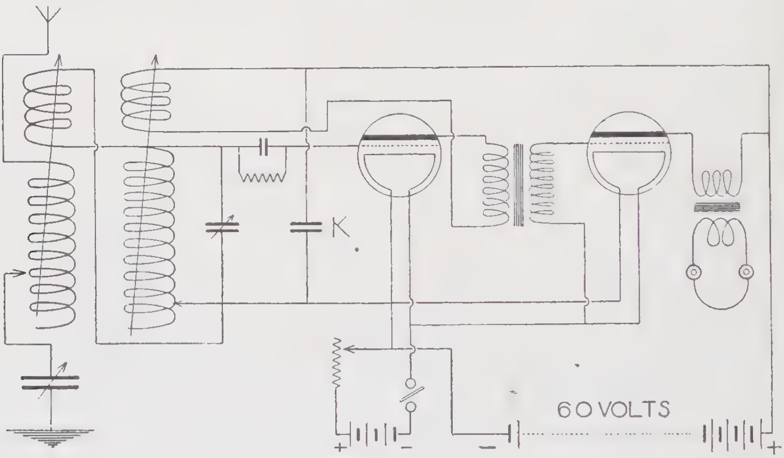


Fig. 163.

of the coil, so that fine gradations of tuning are possible by this method.

If two or more tuned valve circuits are coupled together to give high frequency amplification weak signals may be amplified many hundred times; there is also the further advantage that the tuning will be very sharp and the coupling between the valves can be very loose, so that jamming by spark stations is reduced to a minimum.

The connections for a two-valve ultra-magnifying receiver are shown in Fig. 164; the potentiometer P_1, in the grid circuit of the first valve, is employed to keep down the grid potential so as to work low down on the plate current curve. It is not advisable to try to keep down plate current by using low plate potential;

lowering the plate potential reduces the slope of the curve, thus reducing the amplifying effect.

The plate circuit of the first valve is tuned by a variable inductance and a variable capacity, and the oscillations in it are passed on to the grid circuit of the second valve. This valve has reaction coupling between its plate and grid circuits so that it generates oscillations; thus beats can be formed and amplified. The potentiometer P_2, in the grid circuit of the second valve, brings it to a point on its curve where rectification can take place; it may therefore be replaced by a leaky grid condenser if a French

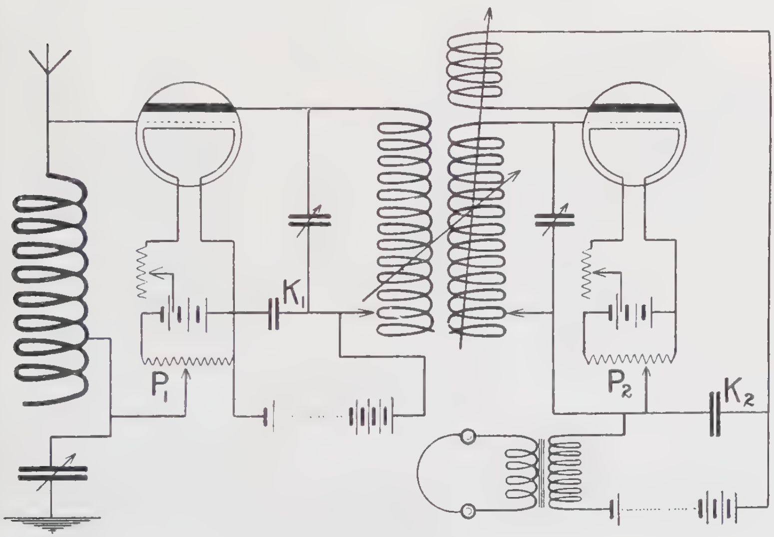


Fig. 164.

valve is employed with 4 volts across its filament. The condensers K_1 and K_2 are especially necessary if the receiver is to amplify very weak signals. It may be considered that with three circuits to tune the adjustments would be very difficult, but it is possible to design the apparatus so that the tuning of the two closed circuits can be carried out synchronously. This can be done by gearing the condensers so that they are adjusted by one handle, in which case the reaction coupling of the second valve should be kept fixed at its best value.

If the local oscillations are generated outside the receiver, by one of the methods already referred to, a simple receiver circuit

will suffice for ordinary signals, and one example only will be given here ; Fig. 165 shows a circuit which could be used when a heterodyning valve is placed in the vicinity of the receiver aerial circuit. To pick up a station the closed circuit coil is coupled tightly to the aerial circuit and the switch S_1 left open so that the closed circuit is aperiodic. The aerial circuit is then tuned in until beats are set up between the oscillations due to the ether waves and those due to the local oscillating valve, the latter having been previously tuned to the proper wave length. The beats will induce beats of the same frequency in the closed circuit coil, which may then be rectified by a detector and passed to the telephones. If jamming from spark signals occurs switch S_1 is closed, the secondary circuit is tuned by the variable condenser, and the coupling made loose. Switch S_2 enables condenser K to be connected in parallel with the tuning condenser so that the wavelength range of the aerial circuit may be increased; this is useful where a comparatively short aerial may be required to pick up long wave lengths. Instead of connecting a detector and telephones across the terminals T_1, T_2 of the secondary circuit the latter may be connected to a 3-valve L.F. Amplifier, in which the first valve can act as a rectifier, such as that shown in Fig. 55.

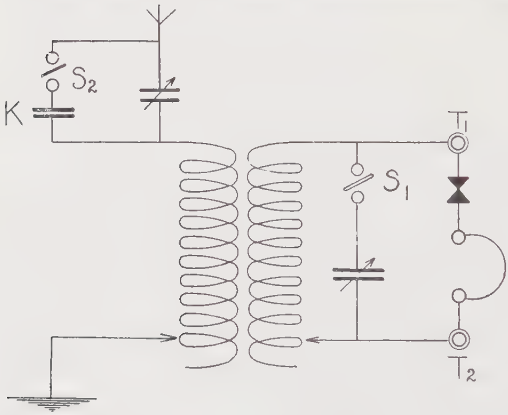


FIG. 165.

The advantages of separate heterodyne reception have already been dealt with in Chap. VIII. : from a practical point of view probably the greatest is that the local or separate heterodyne circuit can be calibrated in wave lengths. Thus it can be quickly set to any wave length on its range, and it can be used as a wavemeter. Another great advantage with separate heterodyne is that the receiver can be efficiently used with very loosely coupled circuits, thus avoiding strong jamming from spark signals.

High Frequency Amplifiers of the French design, such as those shown in Figs. 40 and 42 can be employed very successfully on

C.W. receivers ; the valves can be made to generate oscillations by a suitable amount of condenser reaction between the first grid and last plate ; also, as previously described, these amplifiers tend to amplify weak signals without amplifying strong ones in the same proportion, so that when employed on loosely coupled receiver circuits tuning can be very sharp and spark jamming avoided.

Before closing this Chapter it may be interesting to describe some of the circuits used in France by the author for C.W. reception ; circuits which were made up under adverse conditions as regards

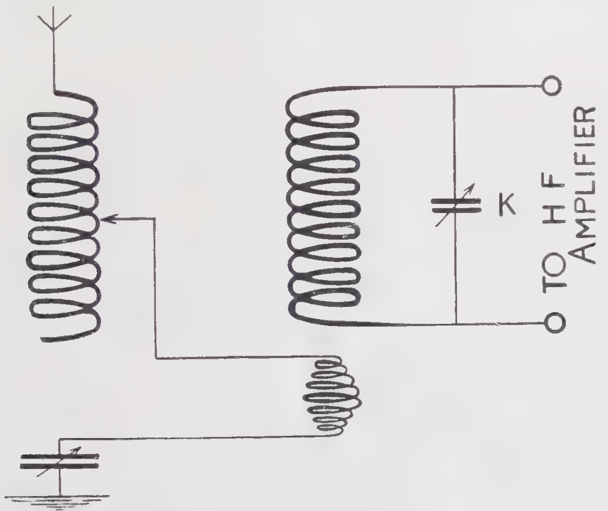


FIG. 166.

supply of material and apparatus but which nevertheless gave satisfactory results. For wave lengths of 700 to 1400 metres a French 4-valve high frequency amplifier, as shown in Fig. 42, was connected to a Marconi panel receiver with loose-coupled circuits. The Marconi receiver gave sharp tuning and it was found that this combination practically eliminated all jamming. The aerial tuning inductance had a maximum value of about 630,000 cms. and the aerial tuning condenser a maximum value of 0·01 mfd. ; the secondary inductance was about 2,330,000 cms. and the Billi condenser could be set to a maximum value of about 0·00045 mfd. The connections are shown in Fig. 166 ; the Billi condenser, shown at K, is of small capacity and gives very accurate tuning. When

using the H.F. Amplifier for C.W. signals it must not be forgotten that the reaction condenser should be varied until the ammeter in the plate circuit of the last valve shows a drop of current, in which case the valves are oscillating. The best potential to employ in the plate filament circuit is about 80 volts, so that the current before it drops is about 1·5 to 1·8 milliamperes. If necessary a L.F. Amplifier can be used after the H.F. one. This receiver was used on an aerial about 60 ft. long and about 25 ft. average height, to pick up signals from a small C.W. transmitter 50 miles away and working on an indoor aerial.

For longer waves a circuit such as shown in Fig. 167 was employed; the A.T.I. was full wound with No. 24 copper wire, with

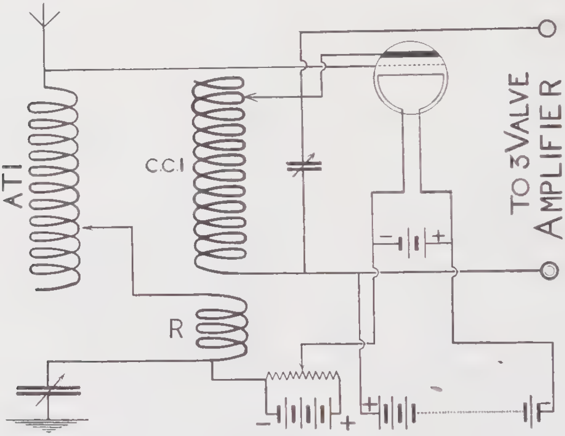


FIG. 167.

eight tappings, on a cylinder made of brown paper 12 ins. long and $7\frac{1}{4}$ ins. diameter. The reacting coil, R, consisted of 80 turns of No. 26, wound on a hard wood cylinder $2\frac{1}{2}$ ins. long and $3\frac{1}{2}$ ins. diameter; it could be moved axially into or away from the C.C.I., and could be rotated so that it was possible to make the coupling very loose. The C.C.I. was wound on a cylinder of ebonite 4 ins. long and $4\frac{7}{8}$ ins. diameter, the coil containing 200 turns of No. 28 silk-covered copper wire with 6 tappings.

The aerial tuning condenser was of 0·01 mfd. maximum capacity and the closed circuit condenser 0·01 mfd. maximum capacity; the latter was too large for really efficient work, but was the only one available. For long wave lengths the aerial tuning

condenser could be connected in parallel with the aerial tuning inductance. The valve was employed only to amplify the oscillations, with a potentiometer in the grid circuit for proper adjustment of grid potential: rectification and L.F. amplification were obtained with a French 3-valve amplifier, of the type shown in Fig. 55, in which the first valve had a leaky grid condenser in series with the grid. With this receiver strong signals were received from such C.W. stations as Portsmouth, Lyons, and Berlin, when used on an aerial 80 yards long, 30 ft. high at the far end and 15 ft. at the near end.

This receiver circuit was not properly proportioned for best working, since the aerial circuit can be tuned to much longer wave lengths than the closed circuit, but the requisite apparatus

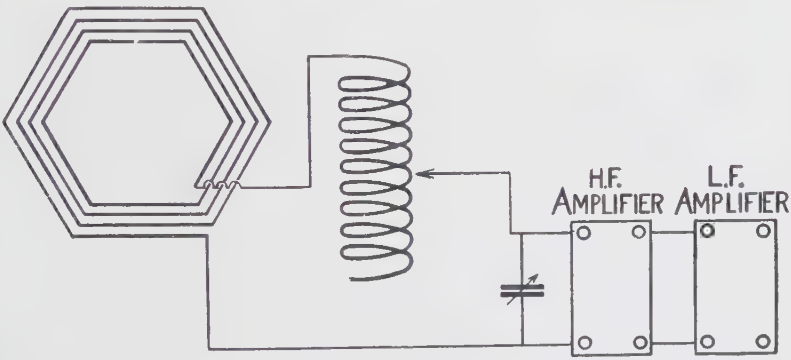


Fig. 168.

was not available and it had the advantage that, by making the plate circuit aperiodic, very long wave stations could be tuned in on the aerial circuit.

For the reception of the official Wireless Press a receiver was arranged in which the aerial and earth were replaced by a coil capable of rotation through 180°. This coil was made on a wooden frame with 6 arms radiating from the centre, each $3\frac{3}{4}$ ft. long; the coil consisted of 22 turns of rubber insulated stranded copper wire threaded through holes in the arms, the turns being spaced 1 inch apart, and the whole resembling a spider's web. This was mounted inside a canvas hut 16 ft. long by 6 ft. broad and 8 ft. high; it was connected in series with an adjustable loading coil with a variable condenser across the total inductance. To the terminals of the condenser was connected a 4-valve H.F.

Amplifier, French design, and behind this was connected a 3-valve L.F. Amplifier.

The arrangement is shown in Fig. 168; with it loud signals were received from the C.W. stations at Portsmouth, Lyons (5000 to 12,000 metres), and Berlin, while spark signals were equally well received from all the principal press stations, including Coltano and Petrograd.

By a proper adjustment of the reaction condenser on the H.F. Amplifier jamming could be reduced, and a small hand-wheel was placed near the operator's table by which the frame coil could be directed on any station, the directional effect being very marked. A view of the complete receiving station is shown in the foreground of Fig. 169, where the absence of an aerial will be noted; in the background is another hut fitted with an external inductance frame of the design described above. A note on the design of closed aerial coils is given at the end of this Chapter.

Fig. 170 is a diagram of a De Forest circuit for the employment of an Audion valve as an amplifier and detector. The circuit is coupled to a receiver circuit which may be an aerial circuit or the secondary circuit of an ordinary receiver. The valve grid is connected to a small series grid condenser with a choke coil leak to the filament. The normal potential of the grid with respect to the filament is adjusted by means of the potentiometer p_1. The plate circuit is completed to the filament by means of a potentiometer p_2; presumably this is set at the potential of the middle point of the filament. One end of the filament is connected to the middle point of the oscillating circuit so that the received oscillations do not influence the filament potential.

The oscillating circuit is connected across the plate and grid; this means that the oscillations change both the plate and the grid potentials by components which are in opposition to each other. Therefore the oscillating and amplifying effect should be very good. The value of the choke leak should be chosen so that the valve does not generate oscillations at audible frequency.

When aperiodic H.F. Amplifiers are employed on C.W. receivers considerable trouble will be experienced from spark jamming unless a direction-finding aerial system is employed. To get over jamming troubles Capt. K. Tremellan employed the arrangement of circuits shown in Fig. 171. He used a Marconi type compass of the usual pattern, with triangular aerials at right angles to each other on a 40 ft. mast; the search coil S was

FIG. 169.

shunted by two tuning condensers in parallel, K_1 was the usual

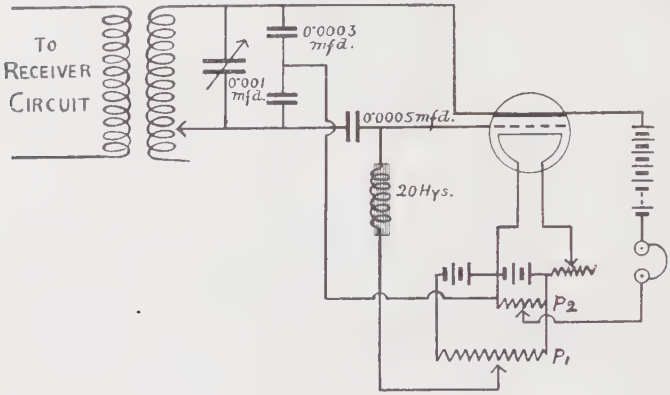


Fig. 170.

Marconi pattern with ebonite dielectric and maximum capacity of 0·01 mfd.; K_2 had a maximum capacity of 0·0003 mfd. K_1

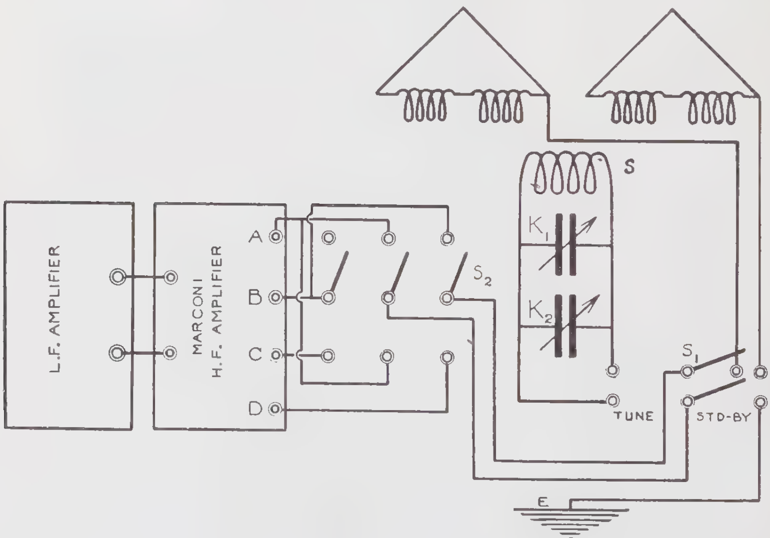


Fig. 171.

gave tuning to wave lengths from 800 to 1800 metres, K_2 gave fine tuning as necessary for C.W. reception.

For Stand By the two aerials were connected together by a switch S_1, which also connected an earth to the other side of the circuit. For selectivity the switch was thrown over and the tuned search coil circuit used. To select for spark or C.W. reception a second throw-over switch S_2 was employed; it is shown in the figure as being used with a Marconi H.F. Amplifier. It will be remembered that this amplifier was fitted with a coil reacting to the plate circuit of the last valve and oscillations could be generated by connecting this coil into the receiver circuit. When the switch S_2 is closed upwards it connects the tuned circuit to the terminals A and B of the amplifier for spark reception, when closed downwards it connects the tuned circuit to A and D, also connecting B and C together so that the reaction coil is brought into action. If the amplifier is not fitted with a reaction coil it is easy to arrange that when the switch is closed downwards it will connect an external coil, which we may call X, in series with S across the grid of the first valve, and a second coil Y, coupled to X, in series in the plate circuit, so that oscillations are generated and C.W. reception made possible.

A L.F. Amplifier can be employed behind the H.F. Amplifier if required. The arrangement is very selective and gives good results as a radio-telephony receiver.

As regards the reception of radio-telephony any good receiver circuit will be suitable, even one with a crystal detector as employed by the early experimenters. It is interesting to note that, where the receiver aerial circuit was inductively coupled to a secondary circuit, these early experimenters, including Poulsen, favoured an aperiodic secondary. The reason of this is that a loose coupled and slightly damped secondary circuit will not well reproduce or follow the microphonic pulse changes in the oscillations owing to its resonance condition.

Where valve receivers are used for radio-telephony beats must not be formed, otherwise they will interfere with the speech reception. We have seen that the sensitivity of valve C.W. reception is greatly due to a negative resistance effect, this being produced by having the receiver rectifying valve on the limit of oscillating at the frequency of the received waves. In this case the beats are formed by a separate heterodyning valve placed near the receiver. For radio-telephony reception the receiver valve can be at the limit of oscillation at the frequency of the received waves since no beats are then set up. B. W. Kendall and the Western Electric Co. have patented an arrangement whereby a local valve

or other oscillator is coupled to the receiver circuit like a separate heterodyne. This valve is made to generate local oscillations at the same frequency as the received oscillations, thus no beats are formed, but if A is the amplitude of the local oscillation and B the amplitude of the received oscillation the variation of amplitude in the aerial is increased as explained in Chap. VIII.

This method is likely to be troublesome in practice, especially on wave lengths of about 1500 metres or less, as the slightest inequality in tuning will cause the formation of beats. This inequality may be caused by the swaying of the aerial or even by movements of the operator. Therefore it is not likely that much advantage can be gained in radio-telephony reception on short waves by a negative resistance effect or by a separate local oscillator.

It is obvious that valve limiters may be employed with advantage in the reception of both C.W. and radio-telephony

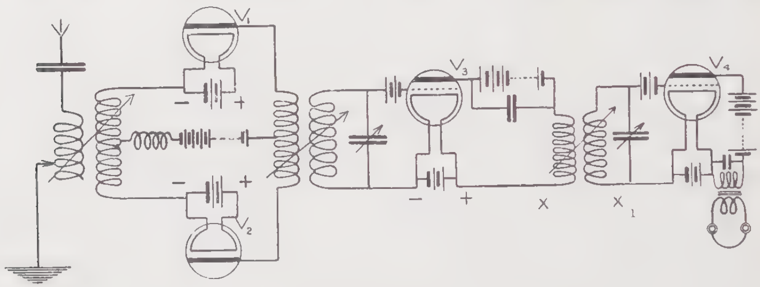


FIG. 172.

signals. To a certain extent the H.F. amplifying valves of the Marconi Co., known as the V. 24 type, are limiters, since their characteristic curves are of short range; therefore a H.F. Amplifier fitted with these valves and interposed in the reception range will help to limit jamming effects. A limiting system may be arranged which is independent of the amplifying circuit; one example of such a system may be quoted.

It is shown in Fig. 172 which is a circuit used by the Western Electric Co., U.S.A., slightly modified. In this circuit two limiting valves V_1 and V_2 of the two-electrode type are employed in parallel so that both half waves of the incoming oscillations will pass through. Their circuit is inductively and loosely coupled to the aerial, and tuned to the same frequency as the aerial. This circuit is loosely coupled to a third circuit tuned to the same frequency, across which is connected an oscillation amplifying

valve V_3. The plate circuit of V_3 is then coupled to a fourth tuned circuit across which is connected a rectifying valve V_4, the plate circuit of which contains the telephone receivers or telephone transformer. If it is desired to form beats a separate heterodyning valve can be coupled to the circuits of V_3 or V_4 by inductive coupling at either of the points marked X and X_1.

This circuit arrangement appears to be very complicated as far as tuning is concerned; however, it must be remembered that most receiver stations are destined to work on one fixed wave length, and the circuits can be designed accordingly with a minimum of adjustment. In any case the condenser adjustments can be geared together so that all the circuits are tuned by the movement of one handle.

It is apparent that a limiting valve of the G.E. Co. or other design, as described in Chap. XI., may be used instead of V_1 and V_2; also that a multiple valve H.F. Amplifier may replace V_3 and V_4.

We may conclude this chapter by reviewing the suitable methods of amplifying signals in a receiver. Where the energy in the receiver aerial is sufficiently strong it is only necessary to amplify the audio-frequency pulses after rectification by a Low Frequency Amplifier; this may consist of one, two or three valves in cascade, and more than three valves should not be employed.

Where the energy in the receiver aerial is very weak recourse must be had to radio-frequency amplification before rectification either by High Frequency Amplifiers, reaction circuits, heterodyne, or a combination of these.

Unfortunately there is a difficulty in using High Frequency Amplifiers on waves shorter than 500 metres, as explained in Chap. VII.; Round got over this difficulty to some extent by a sacrifice of efficiency, designing valves of small inherent capacity reactance and using high resistance wire for his amplifier transformers to prevent inter-oscillations with valves in cascade.

A great advance has recently been made by Matthieu, who has designed a new type of air core intervalve transformer with very small capacity effects between its windings, and great damping of any tendency to inter-oscillation. These transformers are made tunable or astatic, and it is claimed for them that they have increased by threefold the effects of High Frequency Amplifiers.

Again, whilst heterodyne reception before rectification will give good amplification in all cases, yet on waves below 600 metres the beat note is difficult to maintain and becomes more unstable the shorter the wave length.

On account of these difficulties with short wave reception the Signal Corps of the American Army in the French campaign experimented with a system of high frequency heterodyne. That is to say the high frequency (short wave) oscillations in the receiver aerial were combined with the oscillations induced by a separate heterodyne generated to form beats not at an audible frequency, but at a high frequency of 100,000 cycles or more. This high frequency beat was then rectified or amplified by the ordinary apparatus, and as it corresponded to oscillations of long wave length the apparatus was efficient in dealing with it; 100,000 cycles correspond to 3000-metre wave length.

Edwin H. Armstrong has carried out further researches with this circuit, and has obtained remarkable results with it as regards

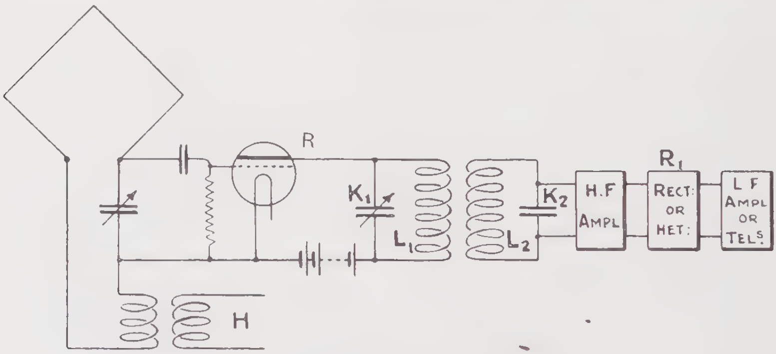


FIG. 173.

amplification and selectivity in C.W. and radio-telephony work. The method of employing this system is illustrated in Fig. 173.

A loop aerial circuit is tuned to the high frequency of the received short waves and coupled to a separate heterodyne H, which may be a valve heterodyne whose filament is heated from the same source as that of the rectifying valve R.

The heterodyne is set to form beats of super-audible frequency corresponding to long wave working; these are rectified at R and supplied to the circuits L_1K_1 and L_2K_2 which are tuned to the super-audible frequency. These pulses are then amplified in the High Frequency Amplifier, which should be of the transformer type rather than the resistance type; and are then rectified at R in the usual manner. For C.W. working it will be necessary to produce low frequency pulses at R by an auto or separate

heterodyne in the usual manner; and if necessary low frequency amplification can be subsequently carried out as shown. The possibility of having two or more stages of super-audio heterodyne is obvious. On spark signals or damped wave it is a peculiarity of this system of super-audio heterodyning that the characteristic note of the transmitting station is not distorted.

Fig. 173A is a view of a modern Marconi Pattern C.W. and radio-telephony outfit. It is a combined Transmitter and Receiver in compact form, equipped with the standard Marconi apparatus.

As regards suitable telephone receivers for radio-telephony it may be remarked that if the diaphragms are light they may respond strongly to one harmonic in the voice and accentuate it, thus making the speech sound tinny in the receivers. On the other hand, if the diaphragms are too heavy the voice harmonics will not be reproduced well and the speech will be muffled. Muffled speech may also be caused by a too heavy microphone diaphragm at the transmitter, or by one which cannot move freely if the carbon granules have become packed behind it.

QUESTIONS ON CHAPTER XIV.

1. Explain with the aid of a diagram why an ordinary detector cannot be employed for the reception of signals on undamped waves.
2. Explain the principles of the heterodyne method of reception.
3. How would you demonstrate the formation of "beats" to a class?
4. What is the difference between separate heterodyning and auto-heterodyning? Compare their advantages and disadvantages.
5. When heterodyne reception is employed C.W. ranges of signalling are much greater than those obtained with spark signalling. Can you explain this from consideration of the effects at the receiver?
6. Draw a diagram and describe the adjustments of a C.W. valve receiver.
7. Explain why the tuning of a C.W. receiver must be very sharp on wave lengths up to 1000 metres.
8. On short C.W. wave lengths the signals are only heard when the receiving tuning condenser is very accurately adjusted, but on very long C.W. wave lengths the signals can generally be heard over a wide range of the condenser. Explain this
9. Write a short account of the reception methods which might be employed to reduce jamming in a C.W. receiver.
10. What are the faults which are most likely to develop in a C.W. receiver?
11. Why is it necessary to have rectification with the heterodyne method of C.W. reception?
12. Under what circumstances may an ordinary crystal detector combination be employed for C.W. reception?
13. How can you tell if a C.W. valve receiver is properly adjusted to receive C.W. signals?
14. What is happening when the valve in a receiver causes a continuous whistling noise in the telephones, and what would you do to stop it?
15. If you cannot receive signals from a wavemeter placed close to your valve receiver, enumerate the order in which you would look for a probable fault.

FIG. 173A.—Marconi ½ KW. Valve Cabinet Set. Transmitter and Receiver for Telephony, Continuous Wave, and Musical Note Systems.

NOTE ON CLOSED COIL AERIALS.

In a pamphlet published by the Bureau of Standards, U.S.A., it is stated that if the waves are sent out by a simple aerial and received on a closed coil, the current in this receiver coil will be :—

$$I_r = \frac{1884 h_s h_r l_r N_r I_s}{R\lambda^2 d};$$

l_r is the length of the coil and N_r the number of turns on it, R is the resistance of the receiving circuit and d is the range of signalling, h_s and h_r are the heights of the aerial and coil, λ the wave length, and I_s the aerial current in the transmitter, all lengths or heights being measured in metres. For the reception of short waves it is best to have a coil of one or two turns of fairly large area, for long waves there should be 20 or 30 turns in a coil of smaller ares. If the coil is a flat spiral a good aperture should be left at the centre as inner turns of small diameter are not very effective. The turns on the coil should be kept slightly apart to reduce the capacitance; at the same time this will reduce the inductance effect and therefore it must not be overdone. A spacing of $\frac{1}{8}$ inch for a 2-ft. coil, $\frac{1}{4}$ inch for a 4-ft. coil, or 0·35 inch for an 8-ft. coil may be used. It must be remembered that a large coil of few turns may have the same inductance as a smaller coil of more turns and it will have a smaller high frequency resistance.

CHAPTER XV

THE DEVELOPMENT OF RADIO-TELEPHONY

Radio-Telephony became possible as soon as radiation of energy was developed on slightly damped or undamped ether waves. The first result of commercial importance was obtained by Poulsen with his Arc Transmitter, when speech communication was established by him in 1909 between Esbjerg and Lyngby in Denmark, a distance of 170 miles. The aerials were 200 feet high, the wave length 1200 metres, and the transmitter aerial energy was 300 watts.

The next notable result was obtained by Prof. Vanni in 1912 when he succeeded in communicating between Rome and Tripoli, a distance of 625 miles. In 1914 R. Goldschmidt communicated from Laeken, near Brussels, to Paris with 3 amperes in the aerial.

The gradual perfection of valves, with consequent increased sensitivity of reception, and the development of high frequency alternators have placed radio-telephony on a sound commercial basis. The outbreak of the war stopped experimental work on long ranges as far as Europe was concerned, but much progress was made in the United States by Fessenden and De Forest, and communication was eventually established between the United States and Paris in 1915. The latter result was not developed or used further during the war, but there is little doubt that radio-telephony will receive much attention in the wireless world within the next decade.

In the two preceding chapters the use of valves in radio-telephony has been described; we will now consider the whole subject on a broader aspect, and deal with those designs of apparatus which are peculiar to this method of radio communication.

Transmitters. -Radio-telephony transmission is attained by setting up undamped or slightly damped oscillations and modulating the amplitude of these in the transmitter aerial by means of speech. Thus any form of generator of undamped or slightly

damped oscillations will be suitable as a basis; this includes Arc Systems, High Frequency Spark Systems, Marconi Multiple Dischargers, High Frequency Alternators, and Oscillating Valves.

The Poulsen arc transmitter the Lepel and T.Y.K. spark systems, the Marconi multiple discharger, and the Goldschmidt high frequency alternator have already been described in Volume I.

Poulsen Arc Transmitters of from 3 to 5 kilowatts input (for wireless telephony purposes) have been constructed by the Danish Poulsen Company, the Lorenz Company, and the Berliner Company of Vienna, but up to the present larger arc units have only been used for wireless telegraphy. The limitation of size was caused by the difficulty of modulating, by microphone control, larger aerial currents than 3 to 4 amperes; this difficulty is now removed by new microphone designs and by the use of valve amplifiers or magnetic relays: at the same time it is doubtful if any great development with arc oscillators will be attempted. This is in view of the fact that microphone control of an arc is not very stable when used as a resistance control, and is likely to cause interference if used as a frequency change control; also the perfection of high frequency alternator design will greatly increase the use of these machines in high-power long-range stations.

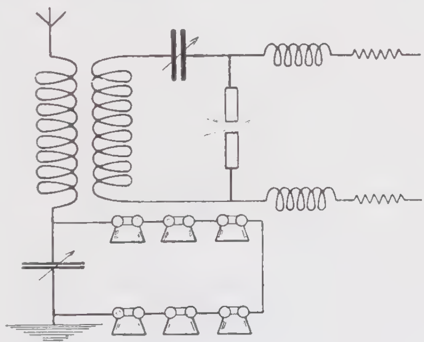


FIG. 174.

For radio-telephony transmission with a small arc outfit Poulsen connected a microphone in series with the aerial ; words spoken into the microphone varied its resistance, therefore modulated the amplitude of oscillations in the aerial. In a second method employed by Poulsen he coupled the oscillating arc circuit inductively to the aerial circuit, and connected a multiple microphone across the tuning condenser in the aerial circuit. This arrangement is shown in Fig. 174, where six microphones in series are connected across the aerial condenser; it is seen that by this arrangement transmission of speech is carried out partly by changing the amplitudes of the oscillations and partly by changing the frequency. Where transmission is effected, either wholly or in part, by change of frequency or wave length, *i.e.*

detuning the aerial, it is important to note that the aerial should not be exactly in tune with the closed oscillating circuit.

When the coupling is fairly loose the resonance curve of aerial current will be as shown in Fig. 175: if the aerial frequency is equal to that of the oscillating closed circuit the aerial current will be 0A. When the aerial is slightly out of tune, and the current is 0B, a slight change of frequency will make a great difference in the value of the current.

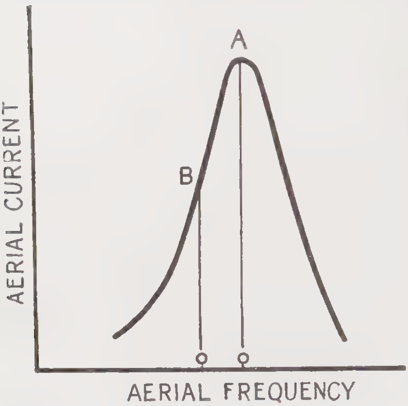


Fig. 175.

Thus the aerial should be detuned by about 5 per cent. so that it is functioning on the sloping part of the resonance curve rather than at the top of it.

The Lepel High Frequency Spark System can be used for radio-telephony. In this case the auxiliary "tone" circuit across the spark gap must be disconnected and a microphone connected in series with the aerial.

The T.Y.K. System of Japan can be used for radio-telephony, indeed several small land and ship stations in Japan have been commercially employed for some years in wireless telephony communication on this system. It will be remembered that the spark gap used in this system has pointed electrodes of small surface section, consisting of minerals such as molybdenite, bornite, iron pyrites, magnetite. One of the electrodes may be of brass. The potential applied to the spark gap is 500 volts D.C. on which the current taken is 0·2 ampere with a resulting aerial current of about 1 ampere. The gap is shunted with the usual oscillating circuit which is coupled inductively to the aerial circuit, a microphone being connected in series with the latter. A high resistance film forms on the surface of the spark electrodes and in order that the spark may strike it is necessary to break down this film. The method adopted is shown in Fig. 176, which is a diagram of the complete transmitter; the electrodes at start must be placed in contact, the high resistance film on their surfaces preventing a heavy current flowing through them. A current then flows through the spark induction coil S; this attracts the armature A which

serves as one electrode holder. The electrodes are thus drawn apart, and the break of the spark coil current at its interrupter induces a high E.M.F. which, acting through the coil and spark gap X in series, breaks down the film on the gap electrodes.

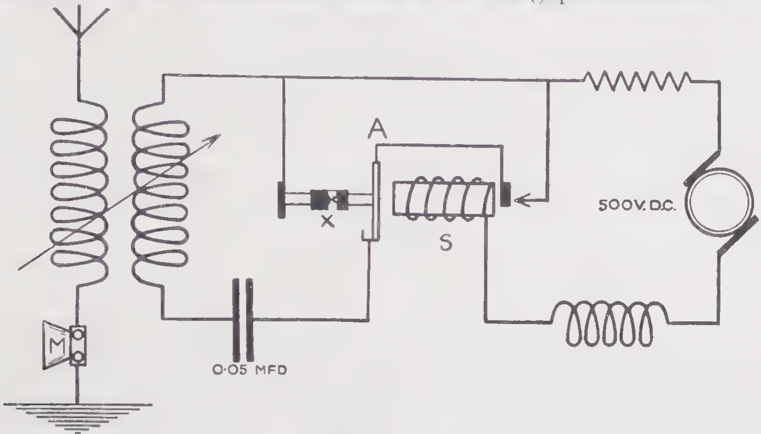


FIG. 176.

The Chaffee High Frequency Spark System, as developed by Dr. E. L. Chaffee, has many interesting features and constitutes a small-power radio-telephony transmitter for ranges up to 100 miles. The gap electrodes are plugs of copper and aluminium, with sparking surfaces of 0·2 to 0·4 square inch area and a spark gap length of 0·04 to 0·09 mm. One of the electrodes is mounted in a holder fitted with cooling fins and fixed in an upright support or circular case, the other electrode is fixed in a similar holder which passes through a phosphor bronze diaphragm clamped against a rubber washer, the diaphragm and case thus forms the spark chamber. The construction is shown in Fig. 177 ; if necessary the spark chamber can be filled with hydrogen gas or alcohol vapour. For larger units the gap consists of an aluminium disc rotating rapidly in front of a stationary copper plate.

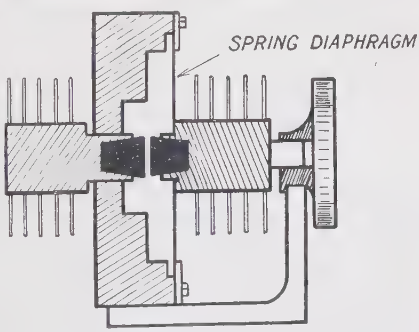


FIG. 177.

Dr. Chaffee emphasises the importance of having the spark frequency a whole-number submultiple of the oscillation frequency, that is to say the spark frequency is exactly a half, or a third, or a quarter of the oscillation frequency. This ensures that the spark will always strike up in phase with the oscillations and prevent a hissing sound in the receiver which may be set up by the beat action of a spark not properly tuned. This synchronising frequency of the spark is sometimes called the "inverse charge frequency effect."

The sparking rate depends on the capacity effect in the closed oscillating circuit and on the strength of the supply current; it can

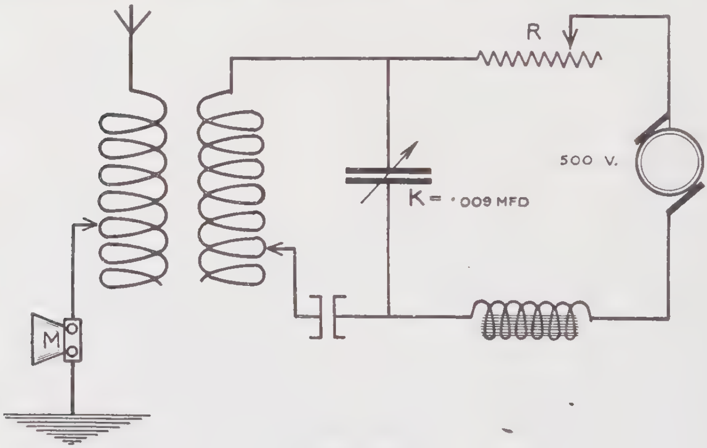


FIG. 178.

therefore be adjusted by adjusting the value of the latter, a fine adjustment being obtained by a proper setting of the spark gap length.

The frequency of sparking is very high and the spark is highly quenched, so that it practically consists of only one-half cycle or loop of discharge current. Dr. Chaffee explains this by saying that the formation of a high resistance oxide film on the aluminium electrode gives a high resistance to the gap when the current is zero. B. Washington's oscillogram seems to prove that the oscillations in the aerial help to re-ignite the spark again by their induction effect in the closed circuit condenser: this keeps the frequency of sparking in proper submultiple step with the oscillation frequency.

With a spark frequency which is one-half or one-third of the oscillation frequency the oscillations are practically undamped, and give a pure C.W. note when heterodyned at the receiver.

The connections for radio-telephony transmission are shown in Fig. 178 ; two gaps may be used in series on 500 volts and four gaps on 1000 volts, the voltage required per gap being about 150 volts. The resistance R must be provided with a fine adjustment, as the spark frequency depends on the strength of the supply current. The radiated energy can be 50 watts per gap with an input of 150 to 400 watts per gap. The design of the microphone M will depend on the strength of the aerial current ; for two gaps in series, on 500 volts, this will be about 1·5 amperes, therefore an ordinary low resistance microphone may be used. The range of a Chaffee transmitter of this type, with two spark gaps in series, is probably about 100 miles, though this will depend on the size of the aerial and design of the microphone employed.

The Moretti Spark Gap was used by Prof. Vanni in 1912 when he succeeded in communicating between Rome and Tripoli, using a transmitter fitted with his own special liquid microphone which will be described later. The negative electrode of the Moretti gap is a copper plate fixed horizontally ; beneath this is fixed a copper positive electrode which has a fine hole bored through its centre and through which acidulated water is steadily pumped. The water rises in a fine jet and impinges on the negative electrode. When a high D.C. voltage is applied and an arc formed the water between the electrodes probably assumes a spheroidal form, vaporising rapidly, and thus extinguishing the arc ; in fact much the same action occurs as in a Wehnelt interrupter.

The sparking frequency is very high and if necessary the gap may be elaborated by giving a rapid movement to one electrode. The circuit used with this spark gap is much the same as those already described ; a 600 volt D.C. generator is connected through choke coils and resistances to the gap, across which is shunted an oscillating circuit inductively coupled to the aerial circuit. The coupling is very close so that the induction in the aerial circuit helps the quenching of the spark. The microphone is conveniently connected in the earth side of the aerial circuit.

The De Forest Spark System has a spark gap in which the electrodes are plates of tungsten very close together, with an adjustment for regulating the spark gap length. Two or more gaps can be used in series in a 1000 volt D.C. generator, or one gap on 600 volts. The circuit arrangements are similar to those already

described, except that in small sets Dr. De Forest employs auto-coupling between the aerial and closed oscillating circuits.

High Frequency Alternators. –The Goldschmidt high frequency alternator has been described in Volume I.: by connecting resonance circuits across the stator and rotor of the machine it delivers to the aerial currents at a frequency which is four times the fundamental frequency of the machine. The Goldschmidt alternators installed at Eilvese, near Hanover, and Tuckerton, in New Jersey, run at 4000 r.p.m. and have 360 poles, the fundamental frequency is therefore 12,000 cycles. Thus they deliver current to the aerials at a frequency of 48,000 cycles per second, corresponding to a wave length of 6250 metres.

The resonance circuits consisting of banks of condensers and inductance coils which must be connected to the stator and rotor of the machine, necessitate elaborate wiring arrangements, and the capacity effects to earth of the leads or the apparatus may seriously decrease the useful output of the machine. Attempts have therefore been made to construct alternators which will have a fundamental frequency high enough for radio-signalling purposes, and much success has already attended these efforts.

The Alexanderson H.F. Alternator is made by the General Electric Company, U.S.A., to the design of E. F. W. Alexanderson, whose first machine, of 2 KW. output and 100,000 frequency, was produced in 1908.

The main electrical features of the design can be seen in the section diagram of Fig. 179; it is an inductor alternator whose magnetising coils are shown at F and armature coils at A, the latter being wound on a laminated portion, L, of the iron core. The rotor is a chrome nickel steel disc, tapering in thickness from the shaft to the periphery so that the centrifugal forces are uniform along its radius. The rotor has slots cut in it near the edge and the slots are filled with phosphor bronze, dovetailed or riveted in and smoothed down. Thus the rotor has an even and smooth metallic surface, and as it rotates the steel teeth between the phosphor bronze-filled slots move through the magnet field between the armature cores, thus providing the alternating induction effect. The side appearance of the rotor is shown at the right of Fig. 179, whilst the magnetic path through the iron is shown dotted in the figure.

The armature is wound with one turn per slot and there are 600 slots for a frequency of 100,000. The rotor is driven direct by a De Laval turbine, or through gearing from an electric motor,

at a speed of 20,000 r.p.m.; this means that the peripheral speed is over 1000 feet per second, or nearly 12 miles per minute, and the peripheral centrifugal force is 68,000 times the weight of the metal at the periphery.

Larger machines of this type have been built by Alexanderson, one of 50 KW. output and 50,000 frequency delivers normally 125 amperes at 400 volts, operating at 3500 r.p.m. The voltage generated will depend on the length of the air gaps between the rotor and stator; in the 2 KW. machine the air gap length is

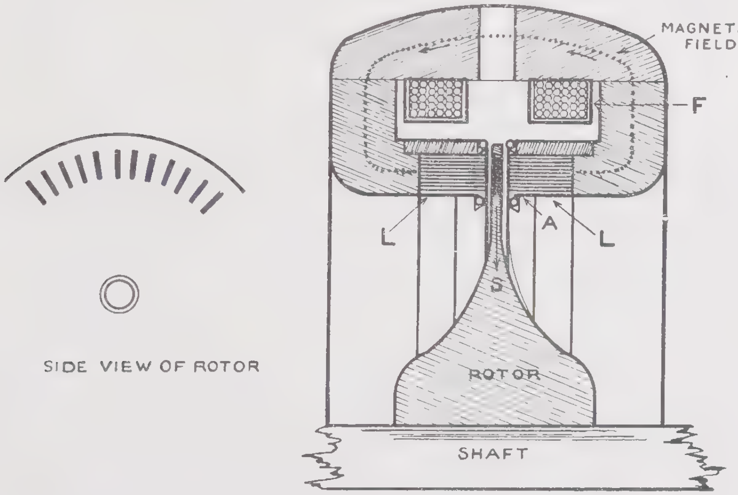


Fig. 179.

0·015 inch and the voltage generated is 150. The voltage would be 300 if the air gap was reduced to 0·004 inch. The machine is connected to the aerial through a step-up transformer; the capacity of the aerial helps to compensate the inductive reactance of the armature winding to bring the circuit into resonance. Thus in the 2 KW. machine the reactance of the winding is 5·4 ohms at 100,000 frequency; it therefore requires a capacity of 0·3 mfd. to produce resonance. The transformer used with this machine has a primary close coupled to the secondary without an iron core: each of the windings consists really of a number of independent coils, with connecting pieces so that the ratio of transformation may be varied. The transformer is said to have an efficiency of 95 per cent.

In the later types of the Alexanderson machine the number of teeth on the rotor differs from that on the stator; thus with 300 teeth on the rotor and 400 on the stator it is possible to obtain the same frequency as 600 teeth on each would give. With equal number of teeth on rotor and stator the magnetic field dies away between the arrival of one tooth and the next; with an unequal number the field dies away as one tooth passes, rises again as portions of two teeth come into action, dies away again as the first tooth goes clean out of action and rises again as the succeeding tooth comes into full action. Thus the frequency is doubled by having unequal numbers of teeth on the stator and rotor. Since the circuit is made resonant for the higher frequency the current at the fundamental frequency is very small.

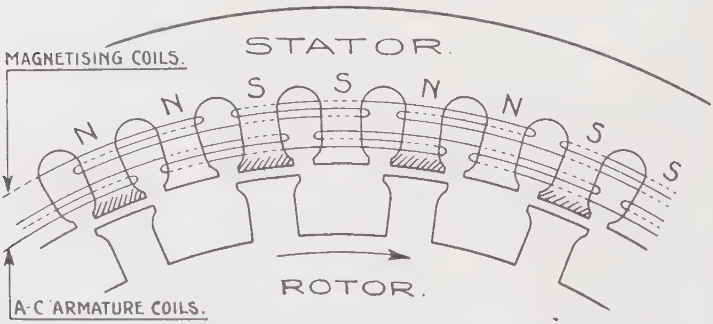


FIG. 179A.

High Frequency Alternators were the subject of French and German patents by MM. Cail-Hermer and Guy. A modification of M. Guy's method was made by M. Osnos and patented by the A.E.G. Co., Berlin. The machine is of the inductor type with both field and armature windings on the stator. The arrangement is diagrammatically shown in Fig. 179A; it will be noted that each pole has got two teeth and that there are half as many teeth on the rotor as on the stator. The armature coils are displaced with respect to the magnetising coils by an angle of 90°, being wound in alternate slots. At the moment depicted in Fig. 179A the rotor teeth are opposite the pole teeth shown shaded; the magnetic flux will therefore cross from stator to rotor by these teeth. As the rotor teeth pass to the spaces between the stator teeth the magnetic flux decreases owing to the increased reluctance of its circuit, to rise again when the rotor teeth are opposite the unshaded pole

teeth. Thus there are two cycles of induction in the armature winding corresponding to each pole on the machine; at the same time the change of magnetic flux through each coil in the magnetising winding is not very great. This method has the advantages of providing good space for both the windings, and of keeping the high frequency induction effects in the magnetising circuit so small that they can be easily dealt with by choke coil reactances of moderate size. High frequency alternators of 15 KW. output and 50,000 cycle frequency are at present being manufactured in France; the number of teeth on the rotor differs from that on the stator, and the machine is of very straightforward design and does not require to be run at excessive speed.

Other Companies have been content to construct inductor type alternators of moderately high frequency, such as 10,000

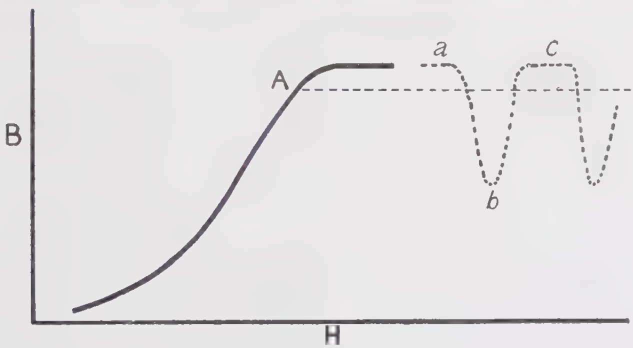


Fig. 180.

cycles per second, and step-up the frequency by frequency raisers. This has been the method used by the Telefunken Company for some years. High frequency machines are most suitably coupled through high frequency transformers to the aerial circuit, as the adjustable coupling thus provided allows the load on the generator to be fixed at the most efficient value.

Frequency Raisers.—Frequency changers have been designed by M. Joly, A. M. Taylor, M. Plohl, and others; those in commercial use at the present time are based on these original designs. If iron is magnetised by a direct current flowing through a coil the magnetising force is represented by H, and the resulting magnetic flux by B. If we plot a curve showing how the magnetisation varies with the magnetising force it will be as shown in Fig. 180; the upper flat portion of the curve corresponds to saturation,

where the flux ceases to increase appreciably with increasing magnetising force. Suppose the core of a transformer is magnetised with direct current so that the magnetic flux is at the value A on the curve, and that alternating currents flow in a separate winding on the core, the resulting magnetisation will be as shown dotted at *a*, *b*, *c*. It is seen that the alternating current sets up rectified pulses of the magnetic flux. The Telefunken Company make use of this effect by the arrangement due to Arco and Meisner; this is shown in Fig. 181. The two transformers T_1 and T_2 have their cores magnetised almost to saturation by direct current from battery B through the coils D; the primary current from the

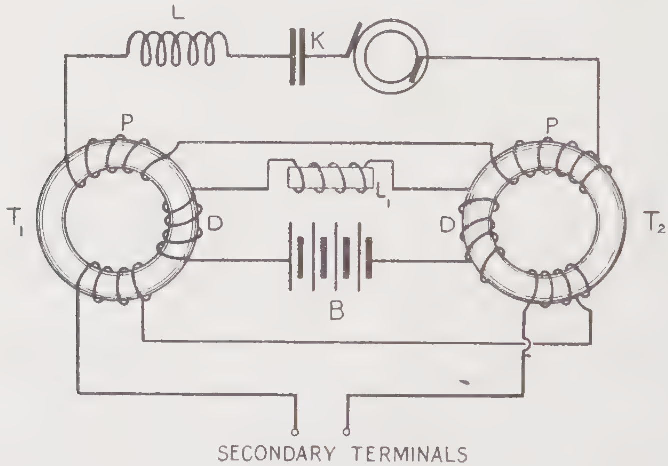


Fig. 181.

alternator is led into the two primaries P which are wound oppositely to each other and may be connected in series or in parallel as circumstances require. The secondaries are connected in series as shown. When alternating current flows in the coils P the D.C. and A.C. will aid each other during one half cycle in one transformer but will act in opposition in the other transformer; when aiding each other the magnetic flux does not rise as the iron is already near saturation, when in opposition the magnetic flux falls. The result in the two transformers and in the secondary is shown in Fig. 182; it is seen that the induction in the secondary is at double the frequency of the primary currents. The coils L and the condenser K help to tune the primary circuit to resonance,

the coil L_1 prevents high frequency currents from flowing in the battery circuit.

If the secondaries are connected to assist instead of opposing

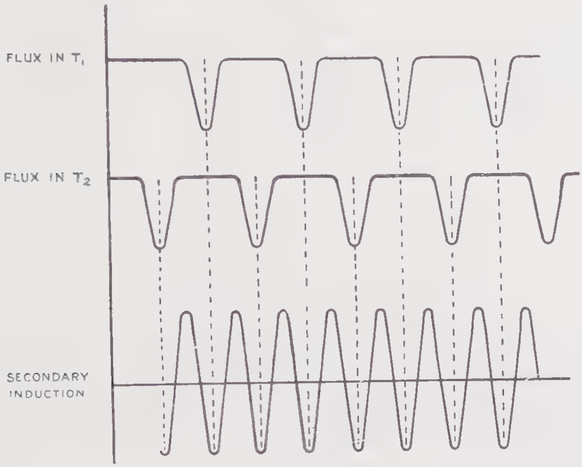


Fig. 182.

each other the resulting frequency would be three times the primary frequency. The secondary is connected to a circuit tuned to the higher frequency, so that the latter is accentuated

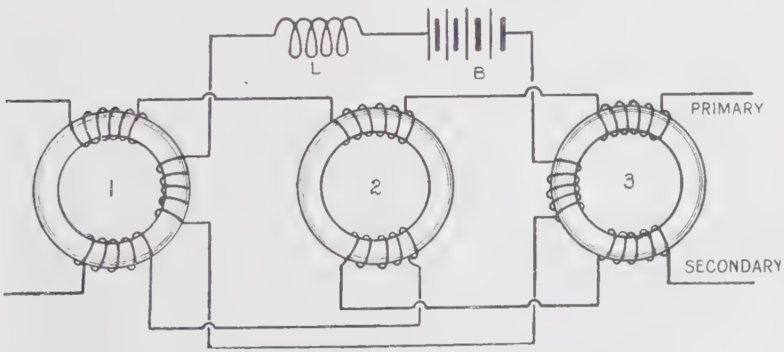


Fig. 183.

while the fundamental frequency is damped. Another arrangement, used in Japan by M. Kujirai, is shown in Fig. 183. Transformers 1 and 3 have their cores magnetised nearly to saturation

by direct current from the battery B through coil L; transformer 2 is not polarised.

The three primaries are in series, or in parallel, but the secondary of 2 is connected in opposition to those of 1 and 3. The E.M.F.s induced in the secondaries of 1 and 3 are asymmetrically distorted owing to the saturation of the iron, the E.M.F. induced in the secondary of 2 is very peaked owing to the low flux density of the iron; the result at the terminals of the complete secondary circuit is an E.M.F. of triple frequency, with a weak one at the fundamental or primary frequency.

Fig. 184 shows the wave form of the E.M.F.s induced in each

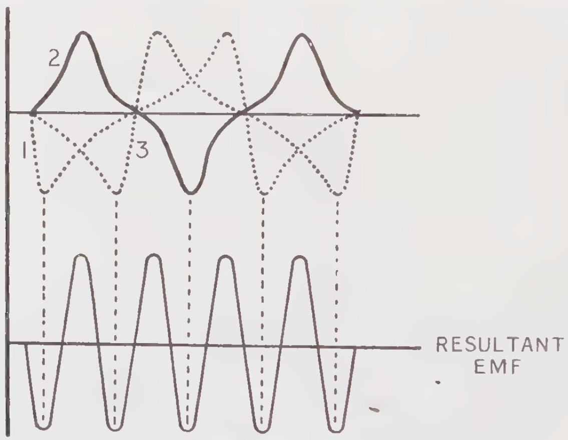


FIG. 184.

of the three secondary windings, and the resultant E.M.F. when the three are connected as described.

A method of doubling the frequency by means of valve rectifiers is shown in Fig. 185; the A.C. generator is connected through the rectifiers to the primary of the transformer, or it may be to two independent primaries. During the positive half of a cycle the valve A allows current through but valve B does not; the current through A gives a pulse of magnetisation to the iron core. During the negative half of a cycle current flows through B but not through A; the current is now reversed but the coil is reversed therefore the direction of magnetisation is the same as before. In other words, we get rectified pulses of magnetisation and if the secondary is connected to a circuit tuned to twice the primary frequency

oscillations of current will flow in this circuit at the double frequency as shown in Fig. 186. This arrangement, with a large condenser

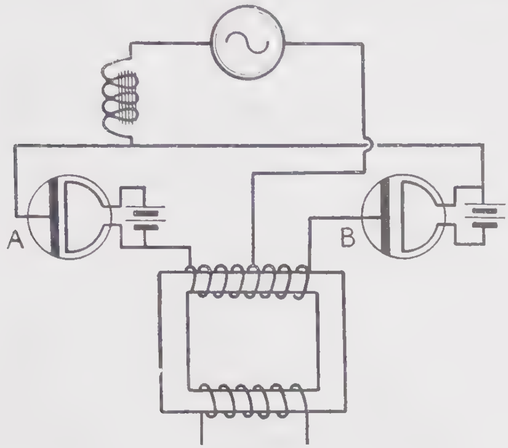


FIG. 185.

across the secondary, can also be used to obtain a steady positive potential on the plate of a valve as used in C.W. transmission.

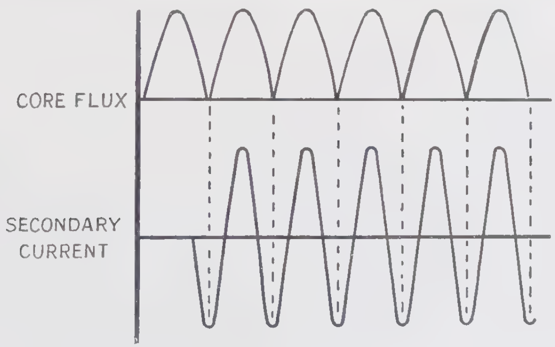


FIG. 186.

Oscillation Generating Methods Compared.—An arc generator does not give a pure sinuosoidal current in the aerial, especially if the arc is a large one, and the combination of arc and microphone gives an unstable control when compared with other arrangements, such as valve oscillators or high frequency alternators.

A high frequency spark system is suitable for small power

plants and ranges up to 100 miles; it has the advantage of simplicity of circuits and uses an ordinary D.C. supply. But unless arrangements are made to time the spark frequency to the oscillation frequency hissing sounds will be heard in the receivers, and in any case with most spark systems the reception is not very clear. It is probable, therefore, that moderate range radio-telephony will be developed with valve transmitters.

Long range radio-telephony will probably be developed with high frequency alternators; considerable transmitting energy will be required as radio-telephony ranges are short compared with those of C.W. telegraphy; if valve transmitters were employed this would necessitate the use of a number of large valves in parallel. The renewal of these valves would be very costly. The high frequency generator of the future will be one which directly generates at the frequency required, without the necessity of tuned stepping-up circuits as in the Goldschmidt system, or frequency raisers as in the present Telefunken system. Whilst these methods radiate energy at the frequency required they also radiate sufficient energy on harmonics to cause much interference with neighbouring stations. The increasing use of wireless communication will demand that stations, especially powerful ones, must radiate on an undamped and pure sinuosoidal wave. By building alternators with a different number of teeth on the stator to that on the rotor it will be possible to obtain high frequency currents with moderate rotor speed. Valves will be employed as adjuncts to these generators in that they will be used to amplify up the microphone control or speech currents before the latter are impressed on the oscillating transmitter circuit.

Microphones and their Connections.—An ordinary microphone consists of a fixed carbon disc at the back and a thin carbon disc in front, the latter being vibrated by the voice. The space between these is loosely filled by carbon granules, held in place by a felt washer whose orifice containing the granules is about 1 inch in diameter. When the front carbon diaphragm is vibrated by the voice the consequent movement of the carbon granules behind it changes the resistance of the carbon path, hence changes the value of any current which may be flowing through the microphone. The microphone case should be so designed that moisture and dust cannot enter; it must be handled carefully as the front carbon diaphragm is thin and very liable to crack.

Ordinary microphones may be made with average resistances of 10 to 100 ohms, and they are capacble of dealing with currents of

0·1 to about 0·5 ampere. As far as radio-telephony is concerned the two great troubles experienced with microphones are packing and burning of the granules. Packing can be avoided to some extent by selecting the granules so that they are of uniform size and preferably sharp-cornered; also by using the microphone in a vertical position. Granules of osmium and platinum alloys have been tried but the change of resistance for a slight displacement is not so great as when carbon is used. Burning of the granules is due to current overload which may weld some of the granules together. Dubilier used microphones in which both the back and the front plates were vibrated by the voice.

We have seen that for small radio transmitters the microphone may conveniently be connected into the aerial circuit near the earth connection; the aerial current will then pass through it, and speaking into the microphone will vary the resistance of the aerial, thus modulating the amplitude of the oscillations and of the radiated energy. The best effect will be obtained if the largest speech vibration varies the amplitude of the oscillations from their maximum value to zero. This is hardly likely to be attained with the resistance changes of one microphone, so that a number of microphones up to six or eight may be used in series to get a good pulsation. The microphones are all connected by symmetrical tubes to one speaking horn, so that the voice effect will be equal on them all. This employment of microphones in series ensures that most of the oscillating energy will be modulated by the speech. Unfortunately, however, the extra microphone resistance in the aerial reduces the oscillating energy for a given primary input, so that the two effects may neutralise each other as regards efficiency.

Since an ordinary single microphone, and microphones in series, are only suitable for use with small aerial currents some modification is necessary when larger transmitting energy is used. The microphone may then be water-cooled at the back, microphones in parallel may be employed, the microphone currents may be used to operate a relay, or special heavy-current microphones may be employed. These methods may be shortly considered, though the modern one of using an ordinary microphone through a valve amplifier or a magnetic modulator control has replaced them all.

The difficulty of using two or more microphones in parallel arises from the fact that the voice may not act equally on them all, one microphone may then carry more of the current than the others, and thus may burn or otherwise deteriorate.

R. Goldschmidt got over this difficulty by the simple arrangement shown in Fig. 187; the microphones, each in series with a coil, are connected in parallel, but the coils, L_1 and L_2, are wound oppositely on an iron core. When the currents through the two microphones and coils are equal there will be no induction in the core; if the current in one microphone tends to be greater than that in the other the out of balance current circulates in the circuit $M_1M_2L_1L_2$, and is choked down by the inductance effect of the core and the coils L_1, L_2.

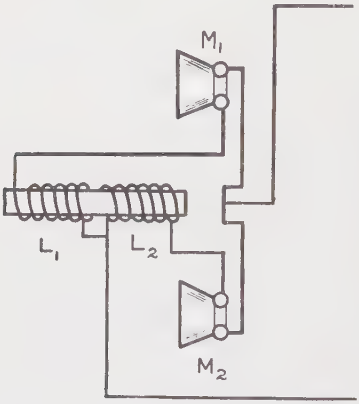


Fig. 187.

Dr. Seibt (Lorenz Co.) stated that for maximum efficiency of signalling the microphone, or microphone combination connected in series with the aerial, should have a resistance equal to that of the aerial circuit before the microphone is inserted, this including ohmic, radiation, and eddy current aerial resistance.

Fessenden in 1906 used a microphone to operate a relay which could deal with large currents, and thus obtained 15 times amplification of the microphone currents. He also used a condenser microphone in which the speech varied the distance between a diaphragm and a fixed plate; this gave a variable capacity effect and, when connected across a portion of the aerial tuning circuit, transmitted signals by detuning.

Microphonic and Magnetic Relays.—To control still larger currents in the aerial circuit special microphones have been designed from time to time. In 1912 Prof. Vanni was able to signal with 12 amperes in the aerial from Rome to Tripoli, a distance of 1000 kilometres, using a special form of liquid microphone relay. This apparatus is shown in Fig. 188. The microphone currents from M acted through a transformer T to an electromagnet E; this vibrated a diaphragm D to which was attached a light lever action L, L. The motion of the lever vibrates an electrode plate X, opposite which is another plate Y arranged as shown. A centrifugal pump P kept up a constant flow of dilute acid which fell as a fine jet from the nozzle N on the plate X, was deflected on to the plate Y, and passed back to the pump. The vibrations of X,

due to speech in the microphone, changed the cross-section and shape of the jet as it flowed between X and Y, thus changing the resistance of the aerial circuit of which the jet formed a part.

Another form of heavy current microphone relay was invented by J. B. Marzi of Italy. In this the carbon, in the form of fine powder, passes between fixed electrodes so that the carbon cannot pack, and is replaced before it has time to get hot. A diagrammatic view of the Marzi apparatus is given in Fig. 189. The microphone currents act through a transformer T on a polarised relay R. The tongue of this relay is attached by a lever arm to a platinum

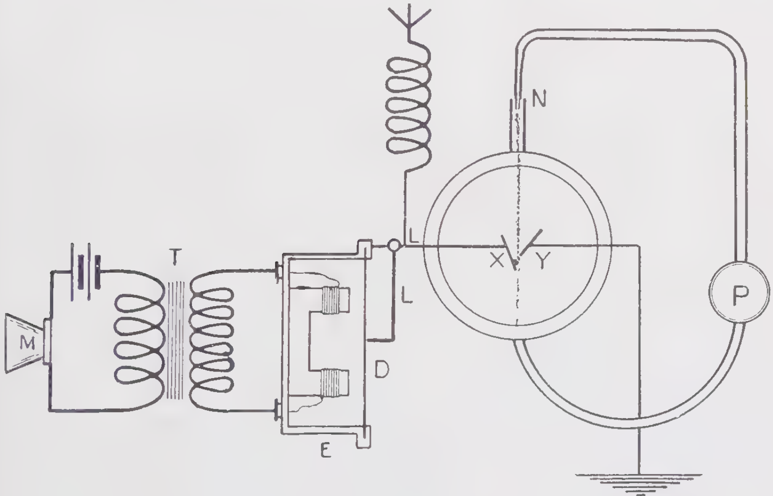


FIG. 188.

electrode p_1, which is close to another electrode of platinum p. Finely powdered carbon falls from the vessel V between these electrodes and finally reaches the lower vessel V_1. The speech vibrations in the microphone M cause the electrode p_1 to vibrate and thus change the value of the carbon resistance between it and p. The carbon powder flowing in a continual stream does not get hot and can be periodically renewed in V from V_1. The electrodes p and p_1 can be portions of two coaxial cones instead of spherical as shown.

This Marzi microphone relay was used by R. Goldschmidt in March, 1914, when he communicated by radio-telephony from Laeken, near Brussels, to the Eiffel Tower in Paris.

Dr. Kühn of the Telefunken Company has amplified the microphone current control by making use of the fact that the permeability of iron changes with the magnetising force. Suppose an iron core transformer is used to step-up the voltage and change the value of a high frequency current; with constant current in the primary the induction in the secondary will depend on the permeability of the iron. If a variable direct current, such as that of a microphone circuit, is passed through an independent coil on the transformer it will vary the core flux, and therefore vary the permeability. This fact is the foundation on which the design of magnetic control relays is based. Induction at the radio

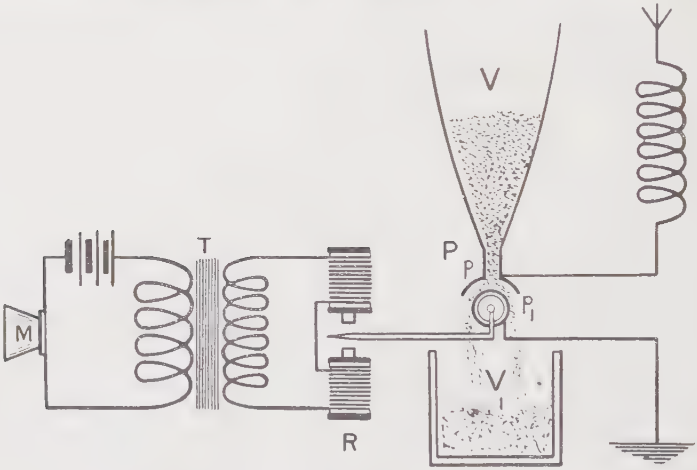


FIG. 189.

frequency will occur in the direct current coil on the transformer, and special precautions must be taken to prevent the passage of high frequency currents through the microphone system.

Special circuits, of large reactance to high frequency currents, must therefore be included in the leads connecting the microphone circuit to the direct current magnetising coil on the radio frequency transformer.

In a system designed by Dr. Kühn for the Telefunken Co. a high frequency alternator was used to generate the oscillations and the frequency was stepped up by transformers arranged as already shown in Fig. 181.

Each of the two transformers was, however, equipped with a fourth coil; these extra coils were connected in series and to a

microphone control circuit. The latter consisted of a combination of microphones in series and parallel, together with the necessary direct current unit. Special radio frequency choke effects were included in this circuit, also in the D.C. exciting circuit, as shown in Fig. 181.

The microphonic currents in the extra transformer windings change the flux in the cores and, therefore, the permeability of the iron; working on a steep magnetisation curve the induction effect in the radio frequency secondary coils, due to small pulses of magnetising force, varied up and down within wide limits. The secondaries were directly connected to the aerial circuit so that the microphone currents not only modulated the aerial current but by changing the secondary induction caused a certain amount of detuning effect as well. By this means 4 watts of microphone output can control several kilowatts of oscillating energy, and the method was used to carry on radio-telephonic communication between Nauen and Vienna. Speech was fairly clear and did not seem to be influenced by hysteresis effects in the iron.

A somewhat similar method was developed by Alexanderson for the General Electric Company, U.S.A. The method requires very careful proportioning of the magnetising forces to obtain a stable control with a fairly steep characteristic.

Valve Relays for Microphonic Control.—Two examples of speech current amplification before it is impressed on the oscillating circuit have already been given in Chap. XIII.; it only remains to give a few typical examples of the use of various valve designs for this purpose. Fig. 190 shows a valve amplifier control, due to W. C. White and used by the General Electric Company, U.S.A. The aerial oscillations are induced by a H.F. generator or by any ordinary arrangement of valve oscillator. It will be noted that the filament of the control valve V may be heated by alternating current as shown in the figure. The plate of the control valve is not kept at a positive potential by means of a battery, but is tapped into a high potential point in the aerial circuit; since the potential in the aerial is an oscillating one the plate will be positive only at positive halves of oscillations, and rectified pulses of current flow through the control valve. In an ordinary case the plate current through a valve, oscillating or otherwise, is drawn from a battery or other external source; in this case it is current which would oscillate in the aerial if the control valve were not connected. In other words the plate current in the control valve represents part of the energy contributed by the

oscillation generator on the left of the figure; thus the current oscillating in the aerial can be varied by modulating the current taken from it by the valve. B is a battery for adjusting the grid potential to a suitable steady negative value, which potential is varied by the microphone currents acting through the transformer T. The condenser K_1 across the grid battery provides a circuit of low impedance to the speech frequency currents in the grid circuit. Owing to the capacity effect between the plate and grid in the valve itself the positive oscillating potentials on the plate will tend to cause positive oscillating potentials of the grid. These would interfere with positive pulses of speech currents: to avoid them

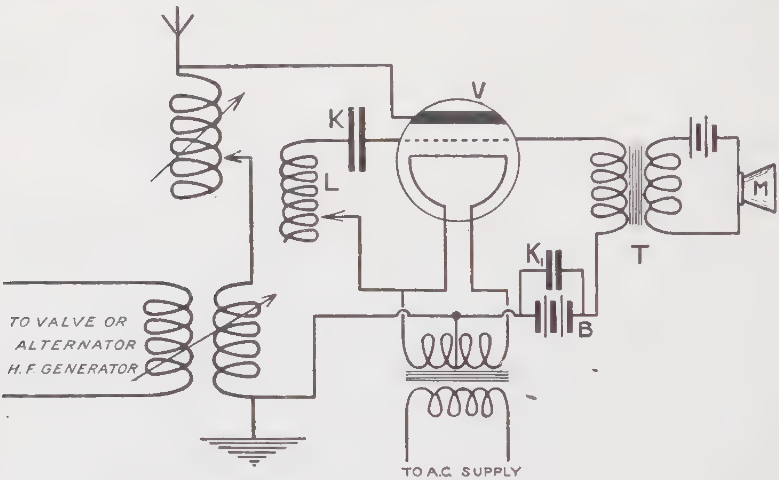


FIG. 190.

the grid and filament are shorted by the tuned circuit LK, which is in resonance with the radio frequency and thus damps out any tendency for oscillating differences of potential to be set up at that frequency between grid and filament.

The G. E. Co. use their pliodynatron valve for radio-telephony transmission, employing a simple circuit as shown in Fig. 191.

The oscillations generated in the circuit LK are controlled by the potentials induced in the grid-filament circuit, the latter having values determined by the microphonic currents acting through the transformer T. The normal grid potential is suitably adjusted by a battery or potentiometer at B, shunted by an audio frequency low impedance condenser path K_1.

In the circuit of Fig. 190 it was noted that the plate of the valve was at positive potential only during positive halves of the aerial oscillations ; in order to make use of both halves of an oscillation, and to get greater plate potential effects, the G. E. Co.

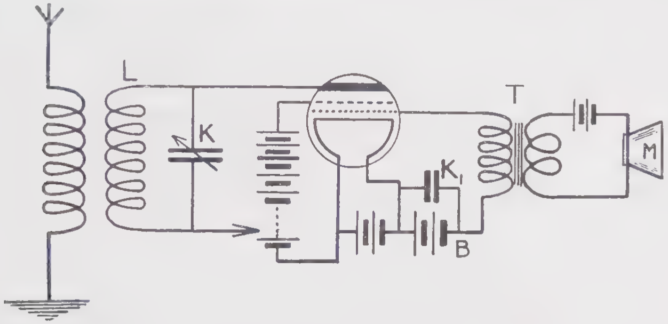


FIG. 191.

have employed a radio frequency step-up transformer coupling between the aerial and plate circuit of a valve with two plates. The connections are shown in Fig. 192 ; a little consideration will

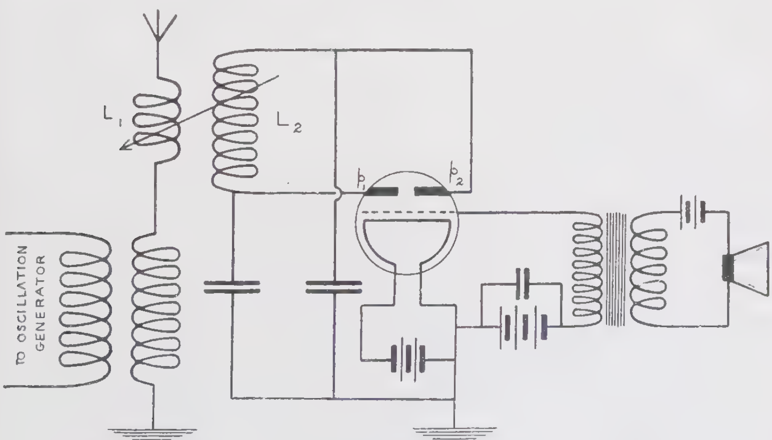


FIG. 192.

show that the plates p_1 and p_2 of the valve come alternately into action, one on the positive half of an oscillation—the other on the negative half. A sufficient value of effective plate potential is obtained by the step-up ratio of L_2 to L_1. The radio frequency

damping circuit from grid to filament has been omitted from the figure for the sake of clearness.

The G.E. Co. have elaborated this method of control by using valves in parallel, so arranged that the amount of energy they can control will be proportional to the square of the number of valves. Briefly this is accomplished by having the control valves under load during only half the time of signalling, so that the energy which may be passed through them without overheating is doubled. With two such valves in parallel the energy handled will thus be quadrupled.

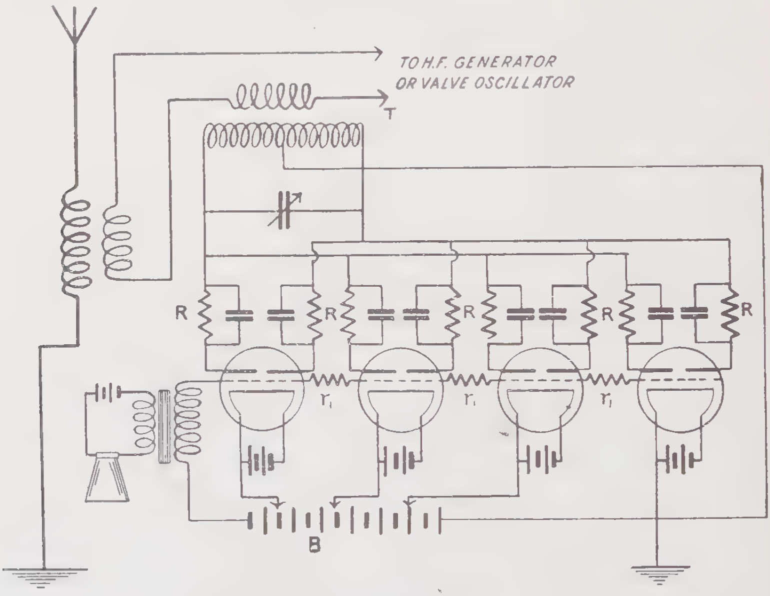


FIG. 193.

The scheme of connections is shown in Fig. 193 ; in this the valve circuits are so arranged that the second valve does not come into action until the first valve is carrying its maximum current, and so on through the succeeding valves.

It is seen that valves with two plates are employed as in the previous case, and they derive their plate potential through a radio frequency transformer T in the generator circuit, the centre of the secondary winding being connected to the filaments. Each plate circuit has a resistance R in series with it, the function of this being to limit the amount of control current which can flow to each

plate. The value of R is chosen so that at a maximum allowed rise of grid potential the plate resistance in the valve becomes negligible compared to R, hence the maximum plate current is $\frac{V}{R}$, where V is the potential difference between the plate and filament. When this maximum is attained most of the energy is being absorbed in R since the resistance of the valve is now small compared to R. The grids are interconnected through resistances r, r_1, and the filaments are tapped to battery B in such a manner that the second grid is more negative than the first, and so on for the third and fourth.

When the microphone is spoken into the control currents flow in the first valve but not in the others, since their grids are more

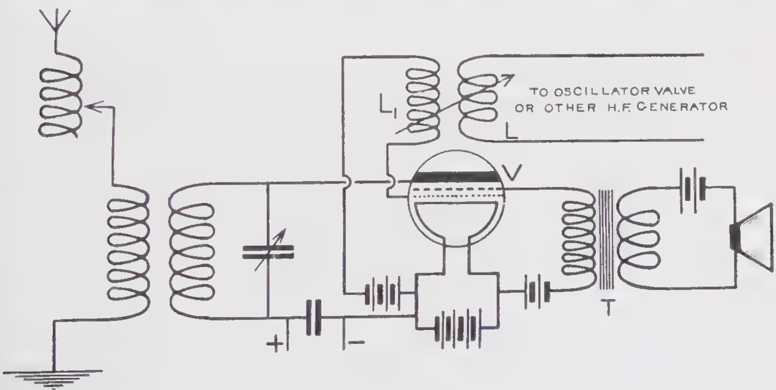


FIG. 194.

negative; when the control current in the first valve has reached the value $\frac{V}{R}$ it cannot rise any higher and current begins to flow in the second valve plate circuit. At the same time the resistance of the first valve between plate and filament is very small compared to R, hence, most of the control energy is in R and not in the valve. This action is repeated through the various valves. In other words, by connecting suitable resistances in series with the plates larger control energies can be handled by the valves, since a considerable amount of it will act in the resistances. The condensers shunted across the resistances are in series with the plates, hence reduce the plate-grid capacity effect and cut down high frequency currents in the valves.

The Western Electric Company, U.S.A., employ a valve with two grids as a control amplifier for small radio-telephony transmitters; this valve is not a pliodynatron. As shown in Fig. 194, the generated oscillations are induced into the ordinary grid circuit of the control valve, V, through the coupling L and L_1: this induces oscillations in the plate circuit current which sets up oscillations in the aerial through inductive coupling. The microphone currents act through a transformer, T, on an auxiliary grid circuit and thus modulate the plate circuit oscillations. This method is preferable to the simpler one of impressing the microphone control on the main grid circuit of the valve; in the latter case the range of grid potential control which will allow the plate

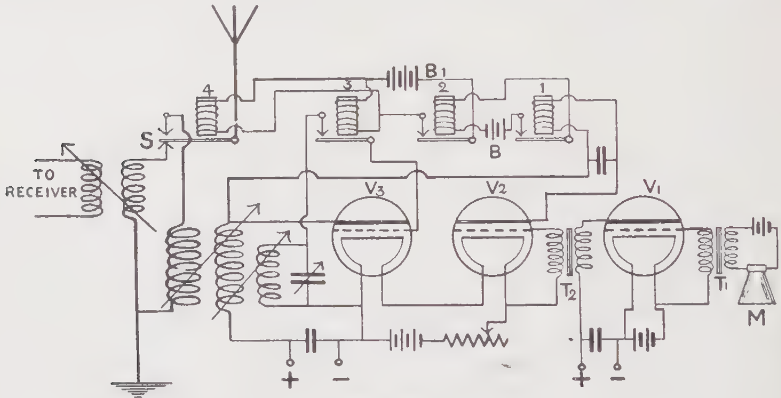


Fig. 195.

current to oscillate over the full range, from zero value to saturation, without distortion and without becoming unstable, is very small.

Breaking In.—The problem of designing arrangements so that a conversation in radio-telephony can be carried on freely is a very difficult one. Ordinarily it cannot be done without changing over from transmission to reception, and *vice versâ;* this is a great inconvenience, and it is desirable that the two communicating people can break into each other's conversation, or give answers, as readily as in ordinary line telephony. A method of breaking in has been patented by the General Electric Company, U.S.A., and a simplified diagram of the arrangement is given in Fig. 195.

The aerial circuit is connected to the transmitter or receiver through the rocking blade S of the relay 4; suppose this is on the reception contact as shown, and that the person listening in speaks

into the microphone; the microphone currents are passed to transformer T_1 and amplified in the valve V_1, passed through transformer T_2 and amplified again in valve V_2. The plate current of V_2 flows through the coil of relay 1 and is sufficient to close the blade contact, which completes the circuit of battery B through the relay 2; this relay closes the circuit of battery B_1 through the relay coils 3 and 4 in parallel. Relay 3 starts the generating valve V_3 by closing its grid circuit; relay 4 closes the aerial circuit to the transmitter coupling.

It is apparent that this system requires very delicate adjustment, but it may serve as a foundation on which future developments can be devised.

From the preceding descriptions it may be gathered that valve control in radio-telephony possesses several great advantages over systems which preceded it. In the first place an ordinary microphone may be used, and it will be connected in a circuit in which the currents never exceed those for which the microphone was designed. This immediately opens up the possibility of connecting ordinary telephone lines to the radio transmitter, so that any one in a large city can speak from his office through the land lines to the radio transmitter and thence across the range of radio signalling. Secondly, the valve amplifier is a stable control without lag effects. Thirdly, it acts generally on the oscillation amplitude and not by detuning, which is a great advantage as detuning methods are liable to cause much interference, especially in view of the future expansion of wireless activity, Lastly, the valve control can easily be adjusted to obtain the most efficient modulation of aerial current amplitude.

It is probable that for long distance radio-telephony the generating unit will be a high frequency alternator and the controlling unit a bank of valves or valve systems. Short and medium ranges will have valve generators, but the renewals expense will prohibit their use, as such, in high power stations.

Thus when radio communication by valves alone was established between Arlington and the Eiffel Tower, some three or four hundred valves were required in parallel to give the necessary power, apart from the banks of amplifying valves, and of control valves between the microphone and the power units.

Fig. 196 shows a small Gen. Elec. Co.-White radio-telephony transmitter which can be started up by simply plugging it to a D.C. supply. It is seen that the filaments are heated from the supply in series with a resistance R; the microphone circuit

draws current from the supply through a potentiometer, P, connected across the latter, whilst the plate circuits of the two valves include the total supply voltage. A portion of the microphone

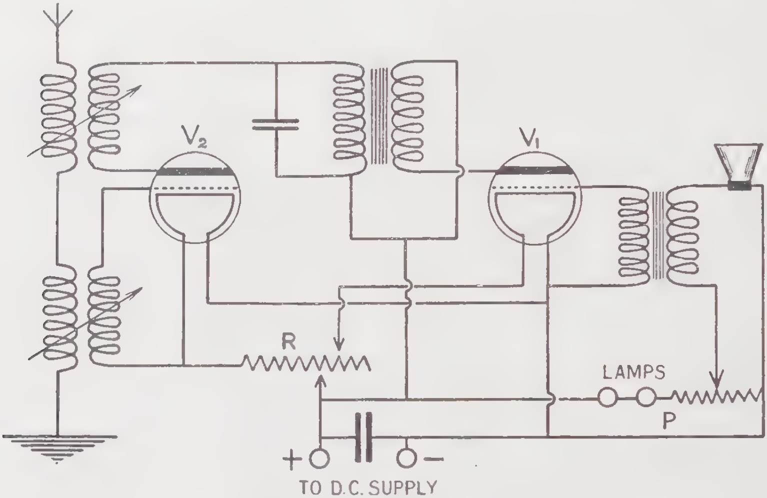


Fig. 196.

potentiometer may conveniently be lamps as shown. The valve V_1 is an amplifier for the microphonic currents, the valve V_2 is the oscillator, its plate and grid circuits being coupled through the aerial circuit.

QUESTIONS ON CHAPTER XV.

1. In radio-telephony transmission what are the disadvantages of having the microphone in the aerial circuit ?

2. What are the likely disadvantages of a system of radio-telephony transmission which employs a high frequency spark in the oscillating circuit ?

3. Draw a diagram of a microphone control arrangement for radio-telephony transmission employing valve amplification of the microphone currents.

4. In radio-telephony transmission what are the possible disadvantages of using a comparatively low frequency alternator and stepping up the frequency through transformers ?

5. The speech received from a radio-telephony transmitter may be (*a*) blurred or drummy, (*b*) tinny. In each case what are the reasons for the distortion ?

6. In a small radio-telephony transmitter why is it not very practicable to modulate the oscillations by having the microphone connected into or coupled to the grid circuit of the oscillating valve ?

CHAPTER XVI

MODERN VALVE APPARATUS

During the period which has elapsed since the termination of the world war the science of radio signalling has received very active attention from an ever increasing band of experimenters in all civilised countries, whilst the number of patents filed for valve designs and valve circuits are almost bewildering in their variety.

These patents are more or less fully dealt with in such journals as the *Radio Review*, the *Wireless World*, and those dealing with the proceedings of different radio societies. In a text-book of this nature no useful purpose would be served in trying to cover a field of investigation which is ever changing; it will, however, give a completeness to this work if a description is given of typical modern apparatus, so that the student may see for himself the latest applications of those principles discussed earlier in the volume.

The Marconi Wireless Telegraphy Co., Ltd., employs a very large staff engaged solely on research and spends large sums annually on experimental work; therefore it is hardly necessary for the author to emphasise the value of a knowledge of their methods and designs.

He is much indebted to the Marconi Co. for its courtesy in placing at his disposal the illustrations and general information contained in this chapter, enabling him, as it does, to describe the latest valve apparatus designed by the Marconi Co. for commercial use.

Marconi Three Kilowatt Valve Transmitter.—This transmitter, designed for radio telegraphy by continuous waves, and for radio telephony, is typical of the most modern designs, being fitted with safety arrangements and operated by a system of remote control.

The transmitter is made up on three standard panels as shown in Fig. 197; on the left-hand panel are mounted the three power valves and below them two rectifying valves, with their accessories at the back of the panel; the centre panel contains the signalling

and relay units, aerial change-over switch and smoothing condensers; whilst the right-hand panel is fitted with the two control valves, one sub-control valve, and their accessories as required for radio telephony. Current measuring instruments are mounted on the top of the panels, and hand regulators for the various chokes are arranged below the panels. As will be seen by the illustration

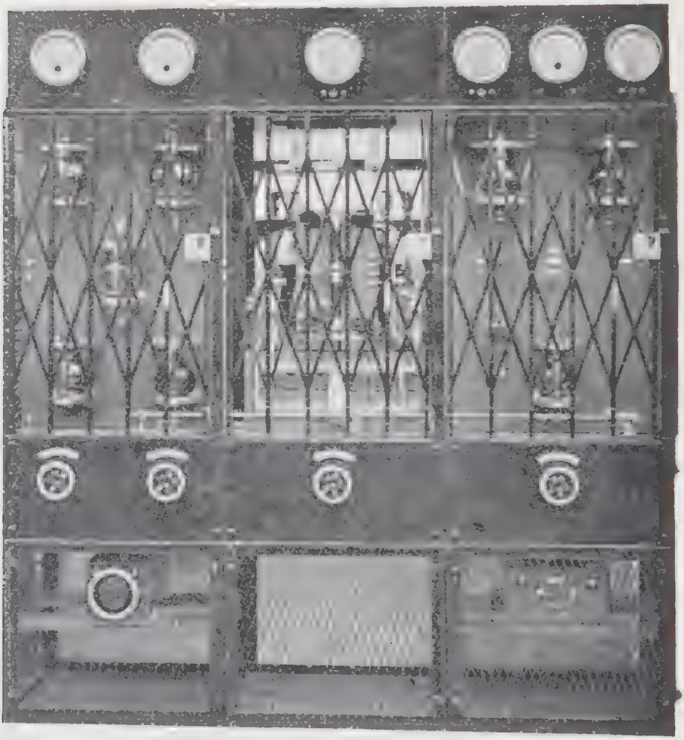


FIG. 197

the panels are completely enclosed by sliding iron gates; if any one of these gates is opened the power supply is automatically cut off from the whole of the apparatus, and at the same time the smoothing condenser is discharged.

The power unit is a motor generator which, in the standard transmitter, generates alternating current at 300 cycles frequency and 300-400 volts; this alternator supplies current to the step-up

transformer that feeds the plate circuits of the power valves through the rectifying valves, also to a step-down transformer, with two secondaries to supply the filament current for the power valves and the rectifying valves respectively. The currents to these filaments are regulated by variable choke coils in series with them, the adjusting handles of these choke coils are shown at the bottom of the left-hand panel in Fig. 197; the alternator also supplies current to another step-down transformer with two secondaries which supply the filament currents of the telephony control valves and sub-control valve respectively. By means of a change-over switch the telephony sub-control valve filament may be fed from a direct current supply.

The standard equipment is designed for transmission on wave lengths from 2000 to 3000 metres, using an aerial of about 0·0015 mfd. capacity and natural wave length of about 750 metres. With larger aerials the transmitter will work on longer wave lengths than those included in the standard range without loss of efficiency.

The Remote Control elements of this transmitter are shown in Fig. 198; they consist of the Morse key for telegraphy, the microphone for telephony, and the switch box, with three switches for telegraphy-telephony change over, send-receive change over, and starting and stopping the motor.

The Morse key controls a relay switch which makes and breaks both the primary circuit of the transformer which feeds the rectifying valves, and the high tension circuit between the rectifiers and the plates of the power valves; when the key is closed the relay also short circuits a compensating choke in series with the primary of the filament transformer, and thus maintains the filament current at a proper value when power is being taken through the valves.

The handle for adjusting this compensating choke is seen below the centre panel in Fig. 197. When the telegraphy-telephony switch is put to "Telephony" it short circuits the Morse key, thus leaving the transmitter in persistent oscillation, at the same time actuating a relay on the centre panel which closes the filament circuit of the telephony control and sub-control valves, closing the high tension supply to these valves, and connecting the speech choke into the anode circuit of the power and control valves. When the send-receive switch is put to "Receive" it cuts off the power actuating the transmission relay, disconnects the aerial from the transmitter, and connects it to the receiver.

The starting and stopping switch controls a relay actuating

the starting handle of the motor, so that the generator can be started or stopped from the operator's table. Thus, with the transmitter gates locked, the whole manipulation of the transmitter for telephony or telegraphy can be completely carried out from the operator's table by means of the apparatus shown in Fig. 198.

The circuit connections on this transmitter are naturally a little complicated by the use of relay switches and remote control; it will be sufficient here to show the essential features of the circuit diagrams.

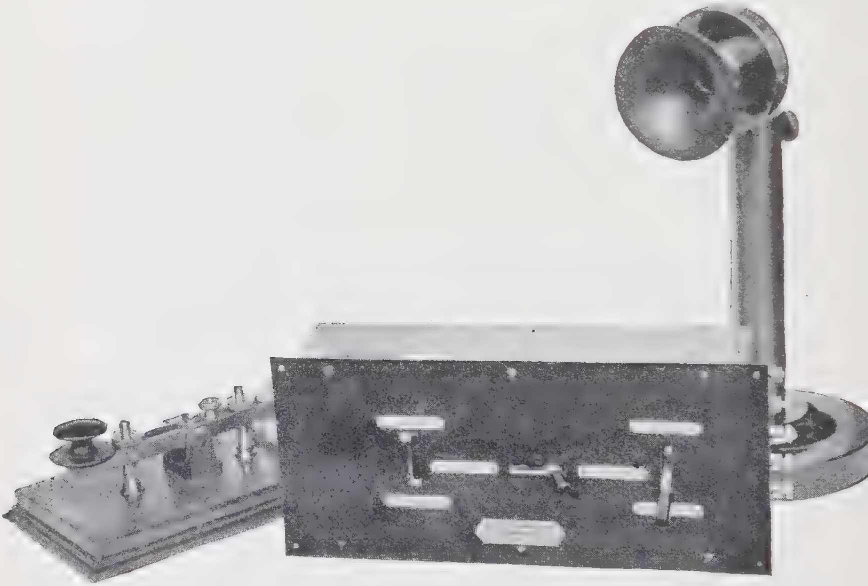


Fig. 198.

For telegraphy transmission with "coupled circuits" the arrangement is as shown in the simplified diagram of Fig. 199; the three power valves have the three plates connected together, the three grids, each in series with a leaky condenser, are in parallel, and the three filaments in parallel. For simplicity only one power valve is shown and the filament heating circuits of the power and rectifying valves are omitted; as previously explained these filaments are supplied through variable chokes from two secondaries on a transformer fed from the alternator. It will be seen that the high-tension transformer and rectifying valves are so arranged as to deliver D.C. supply to the power valves at each half cycle of

the alternating current supply; this arrangement has already been described in Chap. XII. on page 236.

Ammeters are connected through current transformers not shown in the diagram to the filament circuits of the power valves and rectifying valves, the closed circuit, and the aerial circuit.

The necessity for the smoothing condensers and choke, and the air core choke, has been explained in Chap. XIII., and as already described the key relay has other switching effects besides those

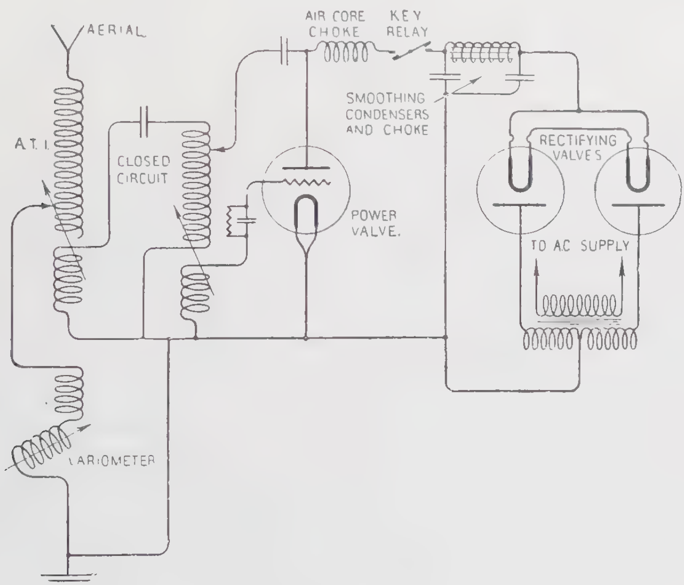


Fig. 199.

shown in this diagram. As regards the oscillating circuits it will be seen that the valve circuit is auto-coupled to a closed circuit and this in turn is inductively coupled to the aerial circuit. If desired the aerial can be directly coupled to the valve oscillating circuit, without the intermediary of the closed circuit; this change can be effected by means of a throw-over switch and plugs on the inductances; when direct coupled the closed circuit inductance becomes the A.T.I. and the closed circuit condenser is disconnected.

For telephony either of two methods may be employed, *i.e.* the "choke" control method with direct-coupled aerial circuit, or the

"damping" control method with the aerial inductively coupled to an oscillating closed circuit.

The diagram of the first method is shown in Fig. 200; here again the filament circuits are omitted, also one power valve only is shown instead of three in parallel and one control valve instead of two in parallel. The plate potential of the power valves, control valves, and sub-control valve are supplied from the main A.C.

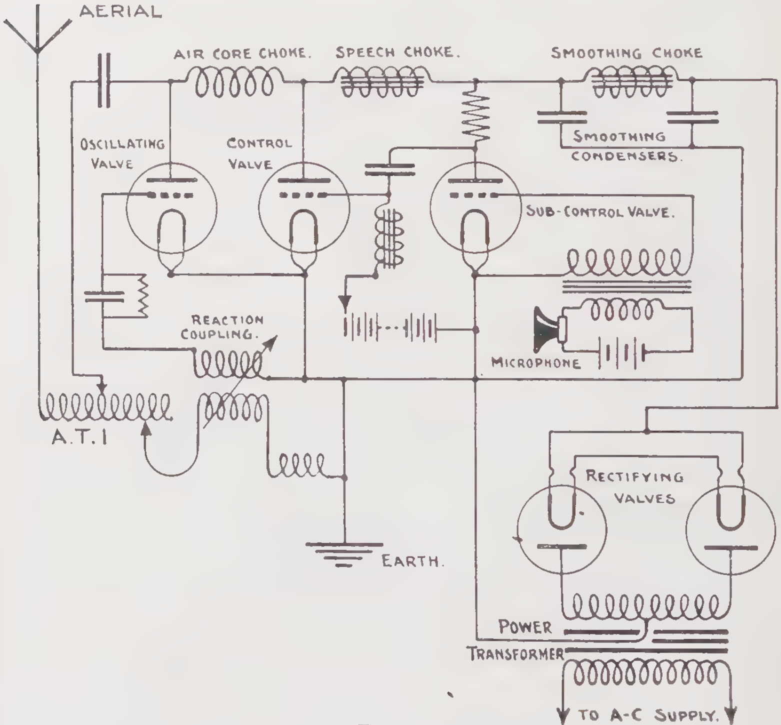


Fig. 200.

supply through the step-up transformer, rectifying valves, and smoothing chokes and condensers. The power valve circuits are in continuous oscillation and direct coupled to the aerial; these oscillations do not get back through the control valve circuits on account of the high reactance to high frequency oscillations of the air core choke. When the microphone is spoken into it pulsates the potential of the sub-control valve grid, therefore varies the sub-control valve plate current. This pulsates the potential of

the sub-control valve plate, owing to the resistance of its circuit, therefore, through the condenser, pulsates the potential of the grids of the control valves, the initial potential of which can be adjusted by means of the battery shown. The choke in series with this battery keeps the pulsations set up in the sub-control valve to the grids of the control valves and chokes them back from the battery filament circuit. The pulsations of potential of the grids of the control valves cause corresponding variations of the plate current of these valves, and since the speech choke keeps the main plate

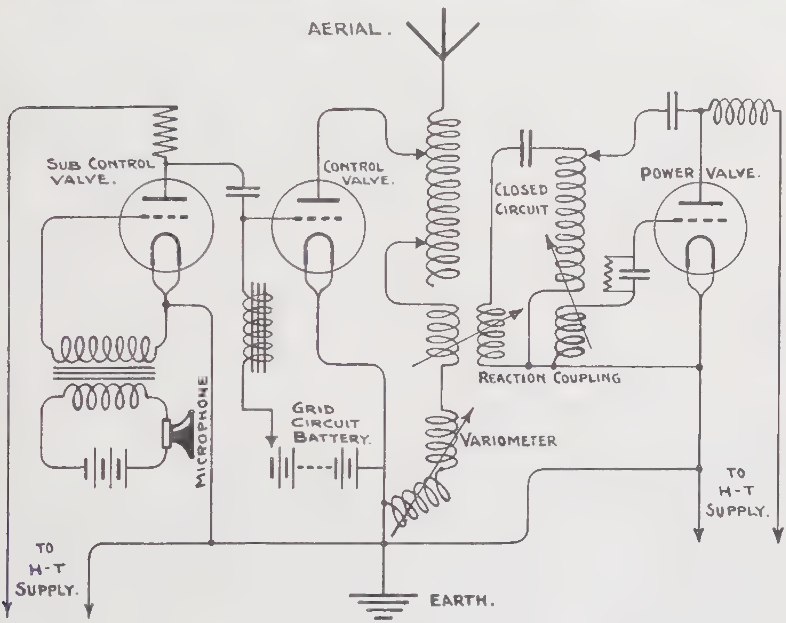


FIG 201.

current at a steady value, these variations cause corresponding variations of plate potential at the power or oscillation valves, so that pulses are impressed on the oscillations, and therefore on the oscillating energy radiated from the aerial.

The principle of the connections for telephony by "damping control" is shown in the diagram of Fig. 201 ; here oscillations are maintained in the aerial, which is inductively coupled through the closed circuit to the continuously oscillating power valves. As before speech in the microphone causes pulsations of the current

in the plate circuit of the sub-control valve, and therefore pulsates the plate potential.

This pulsates the grid potential of the control valves and therefore pulsates the resistance of the plate circuit of these valves. It is seen that this plate circuit is shunted across the aerial inductance, so that if its resistance is varied the amount of energy it shunts from the aerial is varied, and thus the amplitude of the transmitted waves is modulated by speech in the microphone.

The change from "choke" control to "damping" control is made on this transmitter by two sets of plugs and sockets on the front of the telephony, or right hand, panel; one short circuits the speech choke for damping control, the other changes over the anode connections of the control valves. If desired the filament of the sub-control valve can be heated from a D.C. battery through a change-over switch on the telephony panel.

Marconi Receiver or Tuner.—The type now used as a standard by the Marconi International Marine Communication Co. is known as Type 127, and is shown in Fig. 202. It consists of an ebonite panel mounted on a strong teak case which encloses the inductances and condensers, designed to give a wave length range of 300 to 23,000 metres. The Tuner comprises only the apparatus for making up the reception circuits, and therefore it must be used in conjunction with an independent detector, amplifier, or heterodyning equipment as required.

A simplified diagram of the connections of the Tuner is given in Fig. 203; it will be seen that the aerial and closed circuits have auto-transformer coupling through the coil CC, which is common to both circuits; the aerial tuning condenser can be connected in series or in parallel with the aerial tuning inductance by means of a switch S, whilst in the closed circuit a fixed condenser of 0·008 mfd. can be switched in parallel with the variable tuning condenser when it is desired to work on the highest ranges of wave length.

The wave length range of this Tuner is from 300 to 23,000 metres; efficiency at every part of this very long range of wave length is ensured by the design of the inductances.

The aerial tuning inductance consists of eight separate and independent coils, each being for use in its own definite portion of the wave length range; thus normally only one coil is in use at a time, and both ends of all the other coils are disconnected so that "dead end" effects are avoided. A simple diagrammatic

representation of the aerial inductances is shown in Fig. 204 :

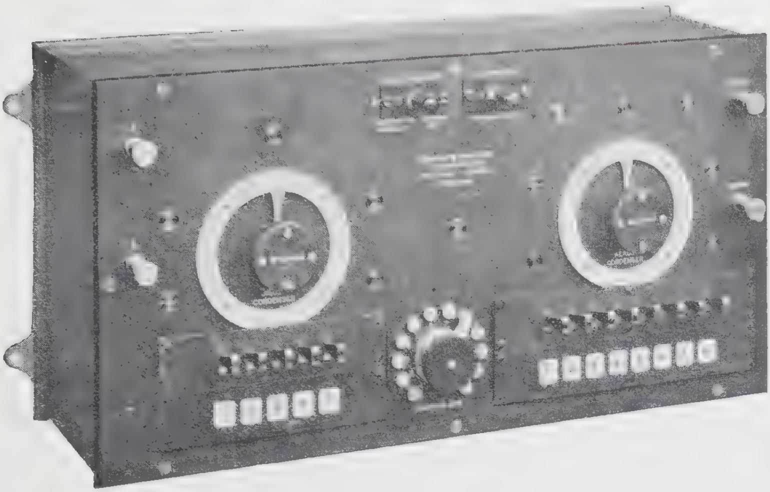


FIG. 202.

each of the eight coils are wound on separate bobbins except the first two which are small coils.

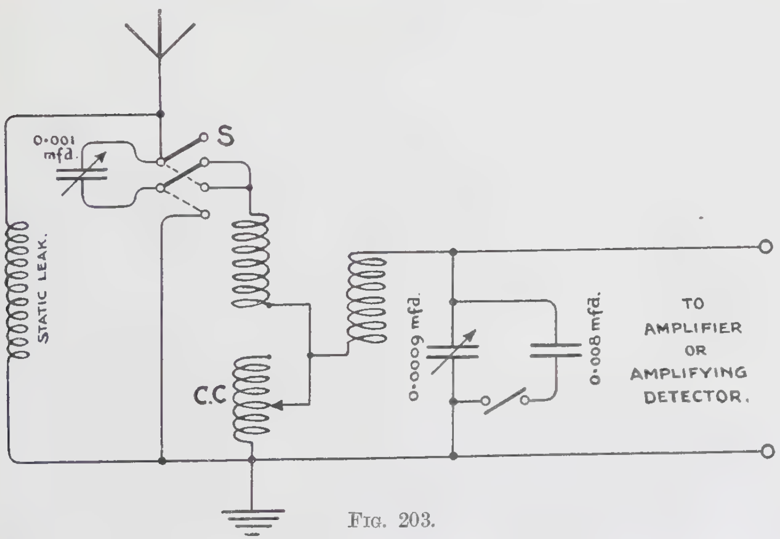


FIG. 203.

A similar arrangement is provided for the closed circuit for

which there are five independent inductance coils of which normally only one will be in use at a time, all the others being entirely disconnected from the circuit. Referring to Fig. 202 the eight key switches in the bottom right-hand corner are for the aerial tuning inductance; they are so arranged that if one is depressed all the others will go back to the off position, though the mechanism provides for the independent working of the keys and the use of two or more coils in parallel if required.

The effect of connecting a second coil in parallel with another is to reduce the inductance in the circuit; since coils are provided to ensure efficient working on all wave lengths within the range it is hardly likely that parallel working of coils will be desirable or necessary.

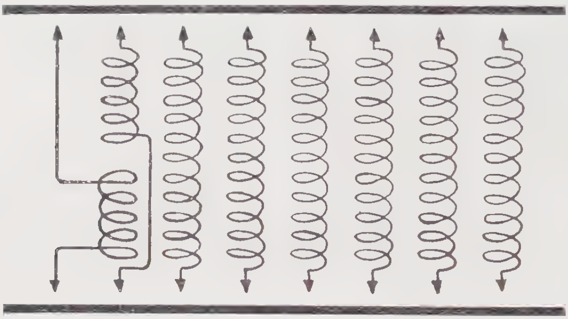


Fig. 204.

The five keys in the bottom left-hand corner manipulate the closed circuit inductances, whilst the 12-point switch in the bottom centre is for the adjustment of the coupling coil. The aerial and closed circuit tuning condensers are in the centre of the panel, and their respective switches are seen at the top centre of the panel.

It is of interest to note that the aerial coils, the closed circuit coils, and the adjustable coupling coil are enclosed in three separate copper-lined apartments in the case, so that stray reactions between these portions of the circuits are avoided.

To use this Tuner the closed circuit is first adjusted to the wave length desired, by using the calibration table provided, the coupling is set at its maximum, (stud 12), and the aerial roughly tuned. As soon as signals are obtained the coupling should be made as loose as possible whilst the circuits are being accurately tuned.

Marconi Valve Amplifying Detector. In this piece of apparatus, which can be used with any suitable Receiving Circuit or Tuner, a 4-electrode valve performs all the functions of rectification, high frequency amplification, low frequency or pulse amplification, and to a certain extent elimination of jamming. The valve is something like the Marconi Q Valve in appearance, but it has got two grids, and a diagram of the connections is given in Fig. 205. The filament is heated by a 6-volt battery through an adjustable resistance R_1 and the terminals AB are connected to the receiving circuit. The high-tension battery, of only 24 volts, is connected in the circuit of the second grid G_2, and if the full line circuits are

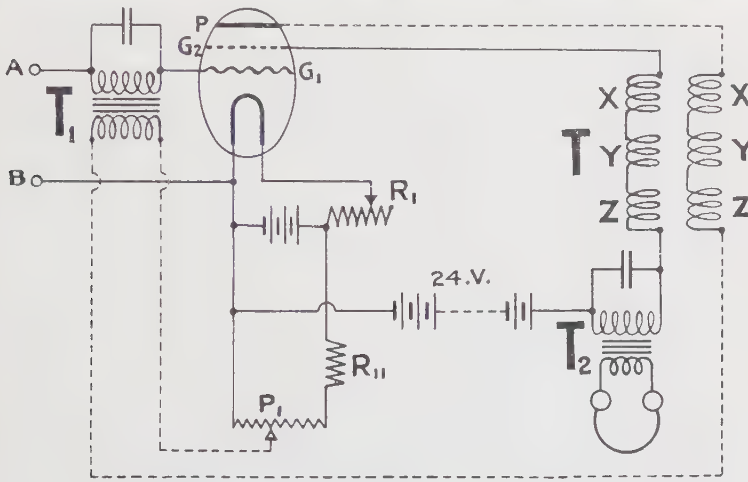


FIG. 205.

considered it will be seen that the filament, grid G_1 and grid G_2, are connected up in the ordinary way for a valve detector, the grid G_2 taking the place of the plate or anode in an ordinary 3-electrode valve.

Thus signals arriving at AB produce oscillations of the current flowing in the grid G_2-filament circuit by reason of the 24-volt battery. These oscillations pass through the primary windings X, Y, Z, of a high frequency transformer T, and through the windings X′, Y′, Z′, are induced into the plate circuit, shown dotted.

Now it will be seen that the plate P is connected through the dotted circuit to the potentiometer P_1 which is connected in

series with an additional resistance R_{11} across the filament battery; thus the potential of the plate can be adjusted to be a few volts above that of the filament and only a small current will flow in the plate filament circuit. In fact the plate filament circuit acts like the original Fleming valve detector, and its characteristic curve is a very small one with well-defined bends at the bottom and at saturation. Now if the plate circuit is adjusted, by means of the potentiometer, to work near one of the bends of its characteristic curve the oscillations induced in its current by the grid circuit through the transformer T will be rectified and form pulses; these rectified pulses are led back into the first grid circuit through the closed core transformer T_1 and are amplified in the circuit of the second grid G_2 which is thus acting now as a note magnifier. The amplified pulses in this circuit pass to the telephones through an ordinary telephone transformer T_2.

As regards the elimination of jamming it can be seen that if, by means of the potentiometer P_1, the plate circuit is adjusted to be functioning at about the centre point of its characteristic curve, rectification of oscillation in this circuit will be more or less annulled, and therefore the oscillations fed back to the grid circuits will not be rectified and no signals will be received. Thus it is possible by adjusting the potentiometer to balance out jamming signals whilst the signals to be received may still be read, though they may be weakened. Weak signals may often be readable where it is impossible to read jammed signals, and the balancing out of jamming signals by an arrangement such as this depends on the quality and strength of the oscillations set up by them, as compared with those it is desired to receive.

As in all cases of high frequency transformation the coreless high frequency transformer T is most efficient on a certain range of wave lengths; in this instrument the transformer consists of three separate sets of windings, X, Y, and Z, controlled by a wave length, or range, switch; on short waves the windings Y and Z, also Y_1 and Z_1 are short circuited by the switch, on medium waves Z and Z_1 only are short circuited, whilst on long waves all three sets of coils are in action; by this means the detector can be made efficient on all waves from 300 to 3000 metres, and gives useful amplification up to 2300 metres with a suitable receiver circuit. The appearance of this detector amplifier is shown in Fig. 206: it is not designed to generate oscillations of itself, and thus if required for use on C.W. signals, a local oscillator or heterodyning arrangement must be employed in conjunction with it.

Marconi Multivalve Amplifying Detectors. The original form of the Marconi 7-valve amplifier is described in Chap. VII.; six of the valves being of the V. 24 type and used for high frequency amplification, whilst the seventh valve is of the well-known Q type and is used for rectification. The great amplification of oscillations obtained by six valves make it possible to use the simplest form of receiver circuit with this amplifier: it may be connected across a simple aerial tuning inductance, or, as previously described,

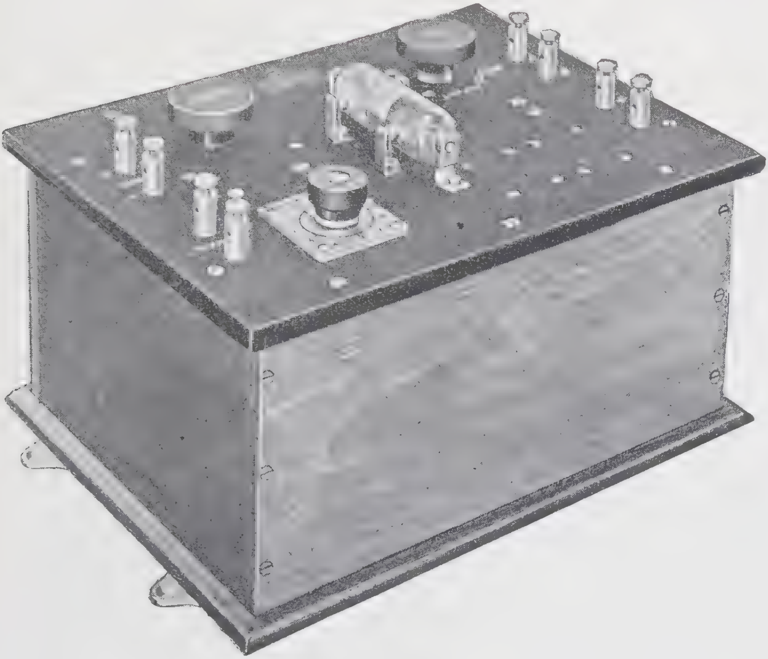


FIG. 206.

quite long ranges of reception may be obtained by a receiving circuit consisting of a directional coil shunted by a tuning condenser and by the amplifier. It will be remembered that high frequency amplifiers are generally most efficient on one given wave length and their efficiency falls off rapidly on each side of this wave length; the Marconi Co. has got over this difficulty by winding the coreless intervalve transformers with high resistance wire consisting of a special alloy, so that the damping of the circuits is artificially increased; thus the resonance effect is reduced and the

amplifier becomes more or less aperiodic. Its maximum amplification is not as great as it would be without this damping, but this is more than compensated for by the number of valves which are employed without difficulty, and, in general, it is more important to have good amplification over a wide range of wave lengths than a high amplification on a very short range. The Marconi Co. makes three designs of this amplifier, each for use on a definite range of wave length, so that a very wide range is covered.

As previously described a reaction coil was provided in the original form of these amplifiers, by adjustment of which oscillations could be generated to receive C.W. signals, or the valves could be adjusted to the threshold of oscillations so as to increase the amplification. In the latest design this coil has been eliminated and arrangements made for reaction through an external coil if found desirable. Such an external reaction coil is connected to the amplifier by taking out the link connecting G and F on the latter and joining the terminals of the coil to G and F. The diagram of the connections of this amplifier is shown in Fig. 207; six V. 24 valves are connected in cascade through high frequency coreless transformers of high resistance winding, and also through condensers. The amplifier is connected to the receiver circuit at the terminals A, B; signals produce variations of potential of the first grid and therefore of the current in the first plate circuit, therefore of the current in the primary of the first transformer. This not only induces a voltage variation through the secondary to the second grid, but also, by reason of the high resistance of the primary, produces a change in the drop of voltage in the primary and therefore of the plate itself. This change of potential is communicated to the second grid through the condenser, so that both the transformer and the condenser are effective in coupling the first plate to the second grid. A similar action takes place through all the high frequency valves and finally the stepped-up oscillations are rectified in the Q valve and passed through the telephone transformer, shunted by its blocking condenser, to the telephone receivers.

The potentiometer enables the initial grid potential with respect to the filaments to be adjusted, and it is shunted by a condenser K to allow the high frequency oscillations to pass. Since the first six valves have to amplify oscillations, and the seventh valve has to rectify, it might be more convenient to adjust the seventh valve independently of the other six, though this increases the number of adjustments.

Such an arrangement can be made with this amplifier by having a small additional box containing a filament resistance and potentiometer for the Q valve, and connecting it to the circuit as shown in Fig. 208; the links connecting E, F, and G, are taken out, and the Q valve filament resistance connected between F and the battery switch as shown at R, whilst the potentiometer is connected from F to the plus side of the 6-volt battery as shown at P_1, and G connected to the slider terminal of the potentiometer.

One advantage of this arrangement is that, without disturbing

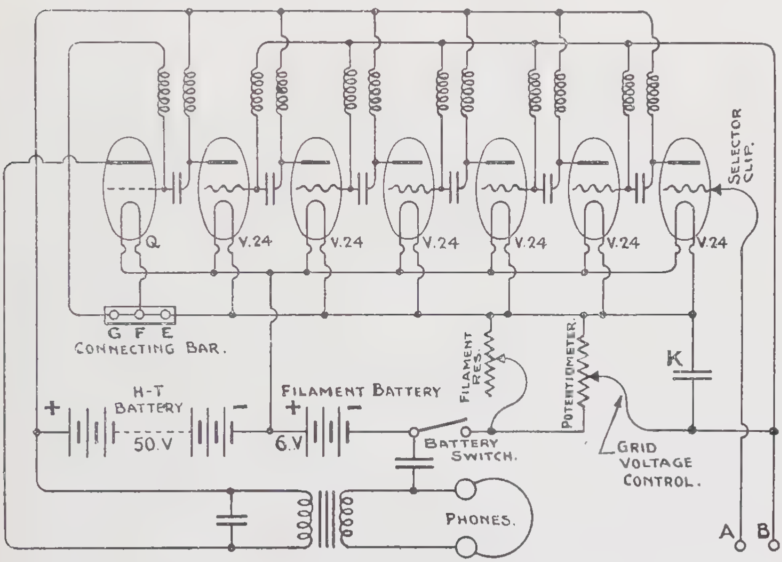


Fig. 207.

the high frequency amplification the Q valve can be adjusted to considerably balance out jamming signals or atmospherics by dulling down its filament and adjusting its grid potential as previously described.

On the amplifier the terminal A is connected to a clip which can be fitted to the grid holder of the first valve, or to the grid holder of any of the succeeding five valves, so that, at will, the stages of high frequency amplification can be adjusted and any number of valves from one to six can be employed for this purpose.

In the amplifier employed for the shortest range of wave length,

that known as TTD, a small condenser is connected between the grid of the third valve and the plate of the fifth: it serves to eliminate a tendency to set up oscillations and is similar in its action to that described in connection with the French design of amplifier in Chap. VII.

Notwithstanding the number of valves employed in these Marconi amplifiers they are wonderfully simple in their operation, and their adjustment is really less difficult than that of a crystal detector; they are very free from microphonic effect, and the almost entire absence of generated oscillations in them avoids

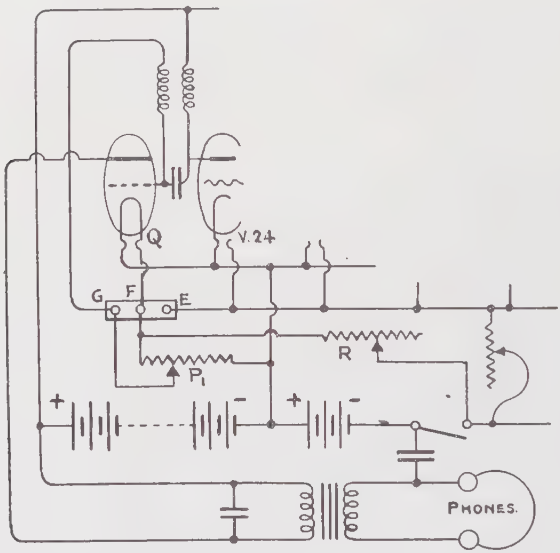


FIG. 208.

interference with neighbouring stations by radiation from the receiver aerial. This is a matter of considerable importance especially in ship work. For use on C.W. signals a reaction coil can be loosely coupled to the receiver aerial, or a separate heterodyne may be employed.

The front panel of this amplifier is already illustrated in Fig. 64, and Fig. 209 shows its interior construction; the six high frequency transformers and stiff wire connections are clearly seen, also the telephone transformer in the right-hand bottom corner.

Marconi Local Oscillation Generator.—This little generator,

shown in Fig. 210, can be used as a wavemeter or as a heterodyne for C.W. signals. A V. 24 valve is employed to generate the oscillations, and since it takes a very small current in both its plate and filament circuits it uses very little energy; also its oscillations when passed into the receiver aerial circuit do not radiate sufficient energy to seriously interfere with neighbouring receivers.

The connections are shown in Fig. 211, from which it will be seen that the tuning condenser can be switched across either the grid coil alone or the grid and plate circuit coils in series, so that two ranges of wave length are obtained. In addition the generator

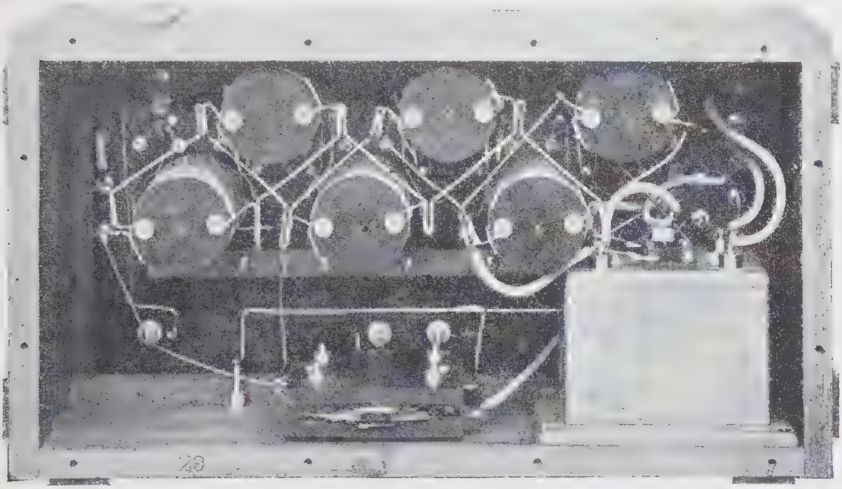


Fig. 209.

is fitted with two interchangeable reaction coils for the plate circuit, so that a further increase of wave length ranges is obtained. The plate and grid circuit coils are of pancake design embedded in ebonite and are connected to socket terminals; the coils are inserted in the circuit by fitting the sockets on the ebonite slab to pin terminals on the panel of the little generator box. A coupling of the usual Marconi spherical shape is mounted in the box behind the reaction coils, and can be connected into a receiver circuit, preferably between the receiver and its earth connection. A 6-volt battery is employed for the valve filament and only five to ten volts are required for the plate circuit.

Marconi Directional Receivers.—The latest design is known as Type 121, and in it are embodied all the most recent modern developments for taking advantage of directional effect, amplification, and selectivity. It can be used for (*a*) non-directional or all-round reception, (*b*) directional reception, (*c*) a combination of both. For all-round reception an open umbrella aerial is used,

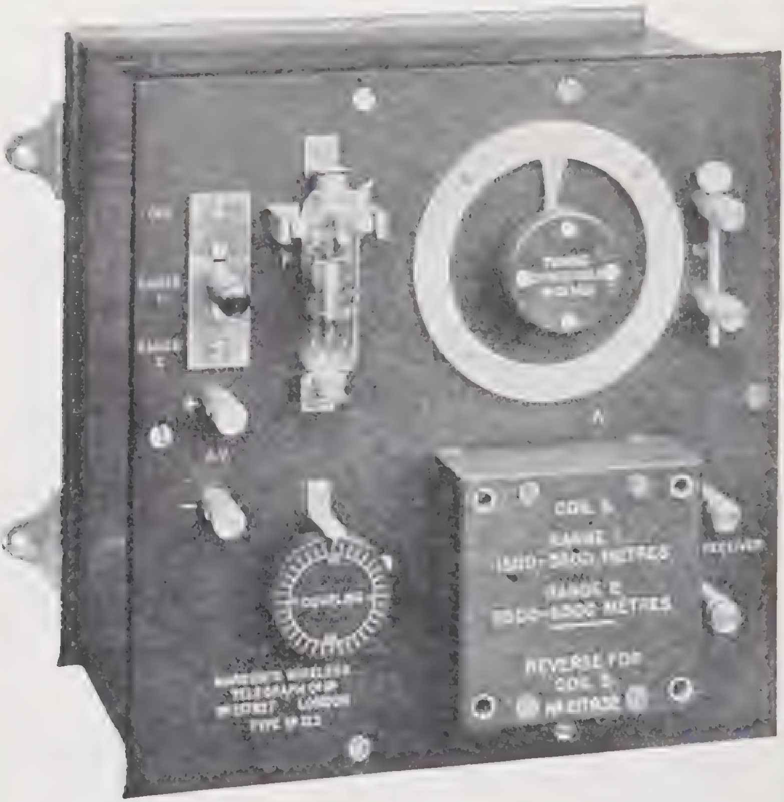


FIG. 210.

the polar curve of energy reception from different directions on a vertical wire or umbrella aerial being a circle. For directional reception the usual Marconi method of having two fixed triangular aerials at right angles to each other is employed, these triangular aerials being supported by the same mast as supports the umbrella aerial so that the whole forms a symmetrical and rigid construction.

The polar curve of energy reception from different directions on such a triangular system is the well-known figure of eight curve.

If it is arranged to receive on both the umbrella and the triangular aerials at the same time then the curve of reception would be a combination of the circle and the figure of eight ; this would lead to no advantage unless the current received on the umbrella aerial was reduced until it was equal to the maximum value of current in the figure of eight curve. Such a reduction is brought about by using an adjustable resistance, called the "phasing resistance" in series with the aerial. The combination now gives a cardioid or heart-shaped polar curve, as shown in Fig. 212, that is to say there is a maximum of signal strength in

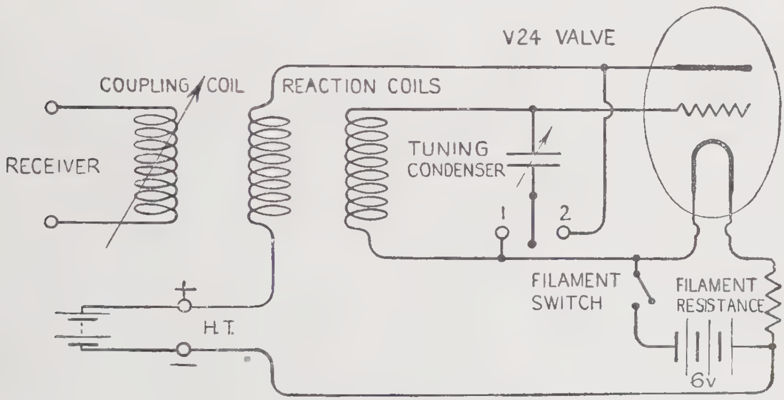


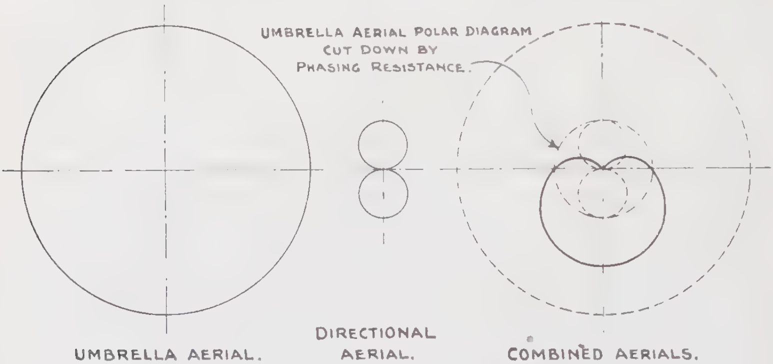
Fig. 211.

only one direction, instead of in two directions as with the ordinary directional aerial.

Atmospherics are largely directional and this combination of aerial can greatly reduce their effect in all cases where the direction of atmospheric disturbance does not coincide with that of the received signals ; it is also a great aid to duplex working where the local receiving station is between the local and distant transmitting stations. It is also claimed that with this arrangement trouble arising from "night effect" is entirely eliminated. The non-directional system is useful for stand-by, rapid searching, and all cases where ordinary tuning methods are sufficient, whilst the ordinary directional system is useful for cutting out disturbances, from directions at right angles to the received signals.

The directional aerial is connected to a Marconi Direction Finder of the well-known pattern; two coils are fixed at right angles to each other in a box, and one of these coils is connected into the centre of the base of each triangle of the aerial. A movable search coil is pivoted in the centre of the fixed coils and is turned through a circle by a handle to which is attached a pointer passing over a graduated scale on the top of the box.

The complete connections are shown in Fig. 213; the small three-way switch near the phasing resistance shows how the open aerial may be connected (*a*) in series with the phasing resistance so that when the latter is adjusted to a proper value the heart-shaped curve is obtained; (*b*) left open so that reception takes



POLAR CURVES OF SIGNAL STRENGTH.

FIG. 212.

place only on the triangular aerials, and the figure of eight curve is obtained; (*c*) joined to the lower contact so that reception takes place on the open aerial, acting through the aerial inductance and coupling coil, and at the same time on the triangular aerials and compass, acting through the search coil. In this case the reception on the open aerial is so much stronger than that on the triangular aerials that in effect the polar circle is obtained.

Fig. 214 shows the complete apparatus; on the left of the lower panel is the Directional Finder or radiogoniometer, next to it is the Aerial Tuning Condenser connected in series with the search coil and coupling coils. Just above this condenser is a three-way switch for connecting in extra block condensers required for the

longer wave lengths. Next to this and on the extreme right of the lower panel is the variable jigger coupling to the amplifier circuit.

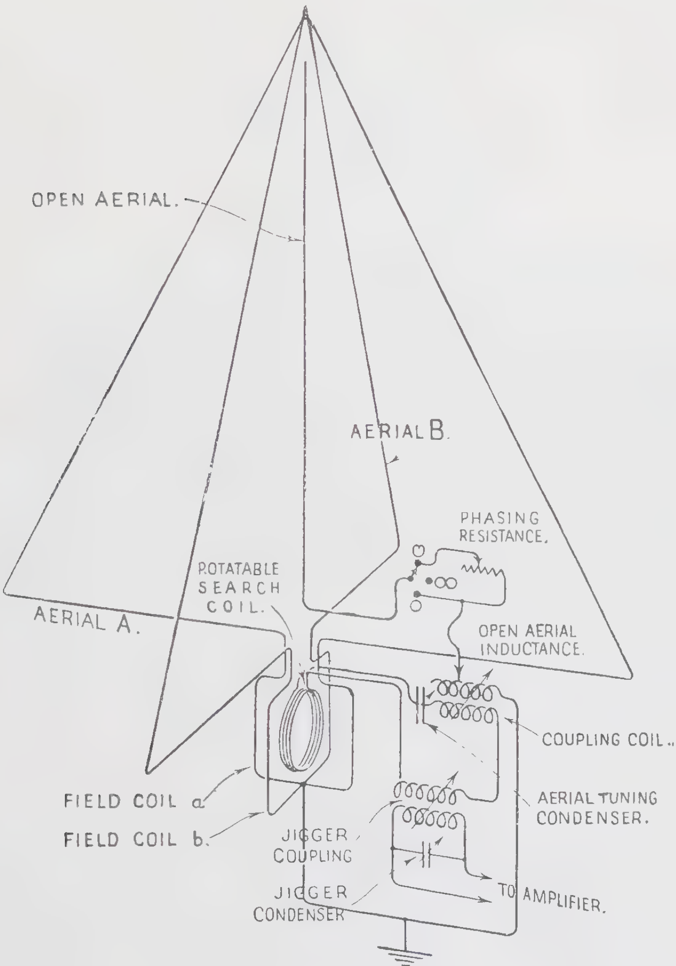


Fig. 213.

On the extreme left of the upper panel is an adjustable filament resistance and a grid potentiometer for the valves of the amplifier, next comes the 7-valve Amplifier, then the jigger circuit

tuning condenser, and on the extreme right a 2-valve note magnifier fitted with a three-way switch whose positions provide for no low frequency amplification, single amplification, and double magnification respectively.

The Robinson Directional Finder.—This elaboration of the ordinary directional coil or "cadre," used in conjunction with high frequency amplifiers, was first employed by the British Air Service; it is easier to instal and accommodate than triangular aerials and is therefore very suitable for ship equipment. As made for ship installations by the Radio Communication Co. of London the reception apparatus consists of a light wooden frame-

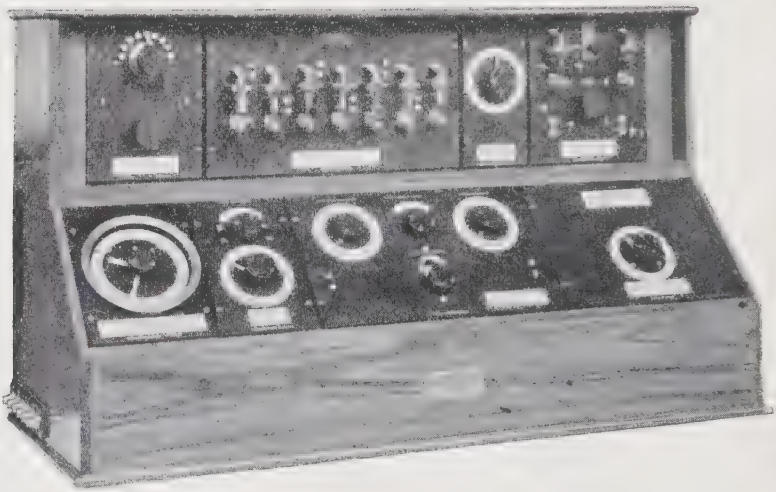


Fig. 214.

work about 2 feet 6 inches square with two windings of thin wire fixed at right angles to each other, the whole revolving on a vertical axis. A complete reception outfit made by the Radio Communication Co. is shown in Fig. 215. As has been explained in a previous chapter, if a simple coil aerial is used received signals are strongest when the plane of the coil is directed towards the transmitting station and minimum signal strength is obtained when the plane of the coil is at right angles to this direction. It is very hard to tell when the signals are strongest or when they are weakest, so that with a single coil an error of several degrees may be made in estimating the direction of a transmitting station;

also minimum signal strength methods have the disadvantage that the signals cannot be read whilst the final adjustment for direction is being made. In the Robinson method the main coil is large enough to give good readable signals when placed in the

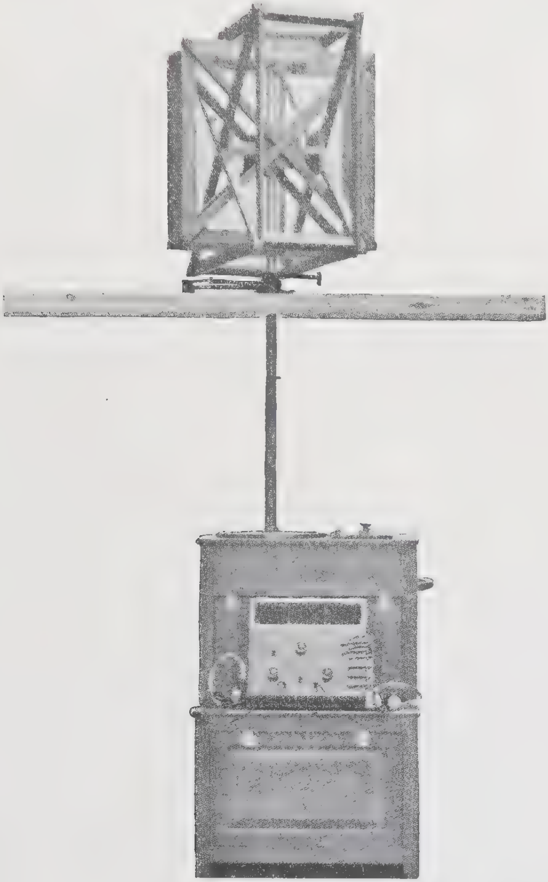


FIG. 215.

position of maximum influence. The auxiliary coil, generally smaller than the main coil, is then switched in series with the main coil and, if it is picking up any energy at all, will strengthen or weaken the signals according as it is acting with or in opposition to the main coil. Thus the method of employment is to adjust

the coil frame until no change of signal strength is made when the auxiliary coil is switched into series or into opposition with the main coil by means of a small reversing switch; the auxiliary coil is then accurately at right angles to the direction of signals and the main coil in line with the transmitting station. It is seen that, in this method, signals are being received all the time that a bearing is being taken, and the comparison of signal strength can be more accurately done than the estimation of a position of minimum strength.

Telephony Transmission for Amateurs.—The Radio Corporation of America, which markets for amateurs the manufactures of the General Electric and other Companies, provides a reliable telephony transmitter of simple design for small outputs from 10 to 100 watts. In this transmitter the microphone acts through a magnetic modulator, a device which utilises the magnetic properties of iron at high frequencies in the same way as the Alexanderson Magnetic Amplifier employed in large transmitting stations, which is operated as a variable impedance connected across the high frequency generator. In a small transmitter the magnetic modulator is connected directly into the aerial near the ground connection; it acts simply as a variable resistance modulated by the microphone, and controls the output of a single oscillating valve without any distortion. The cost of such a modulator is about £3 to £4, which compares very favourably with that of a modulating valve and its accessories: a suitable circuit for use with it is shown in Fig. 216, where the magnetic modulator is shown directly connected into the aerial circuit, and the H.T. supply would be from alternating current supply through a step-up transformer and two rectifying valves as shown in Fig. 139.

If ordinary C.W. transmission is required the magnetic modulator can be short circuited, and a transmitting key connected in series with the resistance leak R for oscillating power up to 10 watts; above 10 watts and up to 100 watts it would be preferable to connect in series with the leaky grid condenser a 1 mfd. condenser and connect the transmitting key in shunt across the latter. It is seen that the above described method of telephony acts by *varying the radio frequency output of the aerial energy*.

For use with a modulating valve and for outputs of 10 to 100 watts the Radio Corporation recommend connections as shown in Fig. 217; this shows one power valve and one modulating valve, the latter requiring a grid battery B_1 of 40 to 50 volts in order that such negative potential may be put on the grid as will reduce

its plate current to a suitable value. X_1 is the high frequency

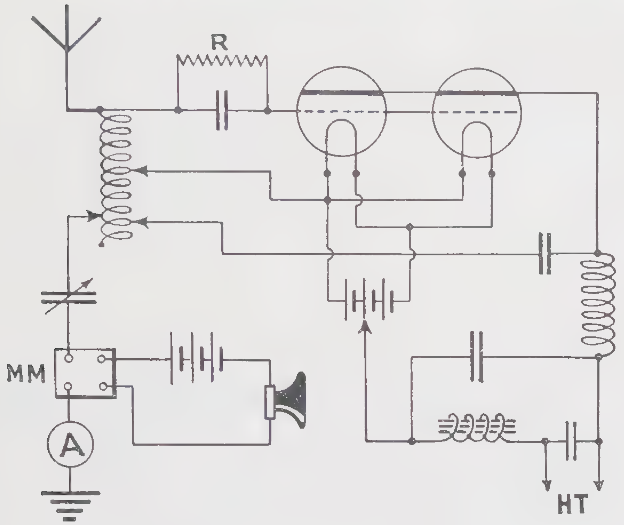


Fig. 216.

reactance, X_2 is the speech choke, and X_3 with its condensers is

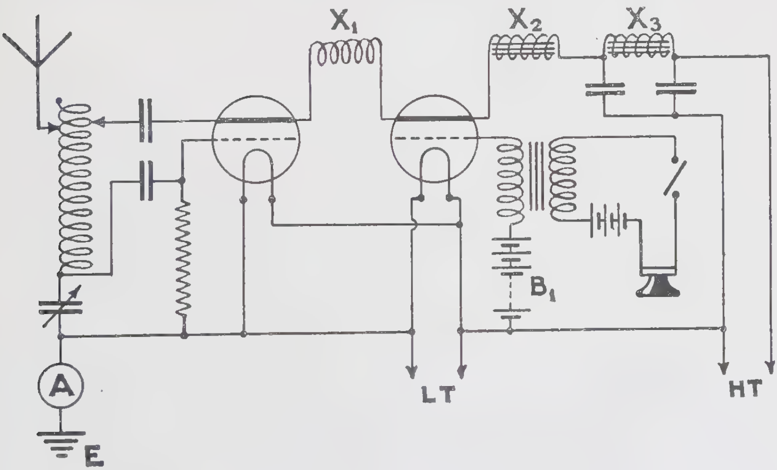


Fig. 217.

the filter reactance to smooth out the H.T. supply, which may be

from alternating current through Kenetron rectifying valves. This method of telephony acts by *varying the input of plate energy to the oscillation generating circuit.*

A very simple telephony transmission circuit suitable for amateurs who do not wish to go in for an expensive system, may be made up as shown in Fig. 218; the H.T. supply should be fitted with suitable chokes, and the grid battery B_1 of the modulating valve should be adjustable. This method of connection *modulates by varying the oscillating energy in the aerial circuit.*

It may be noted that there are three main systems of radio telephony transmission, depending on the method by which the

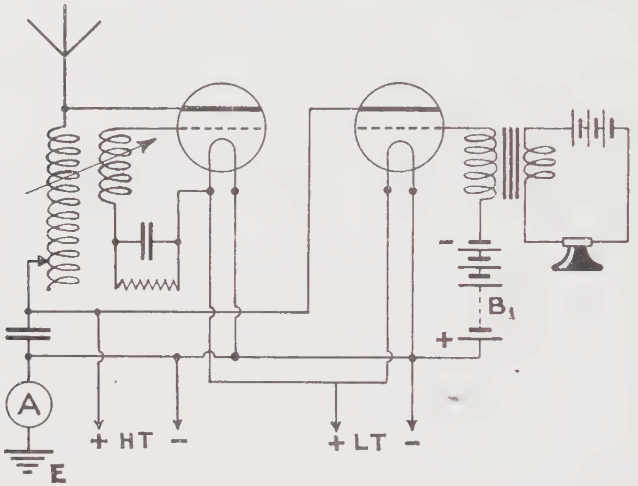


Fig. 218.

microphone is made to modulate the energy; these are:—(1) Modulation by variation of the grid potentials of the oscillating valves, (2) modulation by varying the radio frequency energy in the aerial circuit, (3) modulation by varying the energy of input to the plate circuits of the oscillating valves. The first method is not much used except on very small transmitters, because a modulation of grid voltage has not generally a great effect on the oscillation output; the second method is used by the General Electric Co. of America in connection with their high frequency generators; the third method is the most universal.

In telephony transmitters where two or more valves are

operating in parallel there should be, as a general rule, as many modulating valves in parallel as there are oscillating valves, though it is better to have too few modulating valves than too many because overmodulation causes distortion. Up to the present no satisfactory method of classifying telephony transmitters has been devised, for it must be noted that the reading of the aerial ammeter gives us no indication of the efficiency of the transmission. Variation at speech frequency of the aerial ammeter reading will indicate that speech transmission is taking place, but there might be even more efficient speech transmission at times when the readings of the ammeter are steady.

QUESTIONS ON CHAPTER XVI.

1. Enumerate and compare the different methods of applying microphone modulation to a radio telephony transmitter.
2. Compare "damping" control and "choke" control in telephony transmission. Under what circumstances would the second method be used in preference to the first?
3. What are the advantages and disadvantages of the Robinson Direction Finder compared with the use of fixed triangular aerials?
4. In large valve transmitters why is it necessary to discharge the smoothing condensers before handling any portion of the apparatus?
5. What is a magnetic modulator, and how does it act?

CHAPTER XVII

EARTH CURRENT SIGNALLING

Early Attempts.—The first recorded experiments of electric signalling by conduction methods without wires were those of Morse, who signalled across a canal 80 ft. wide in 1846, and later established communication across the Susquehanna River over a distance of nearly a mile. The arrangements he used are shown in Fig. 219; the transmitter consisted simply of a battery connected by long cables to two copper plates, C_1 and C_2, immersed in the water; the receiver was a galvanometer G similarly connected to

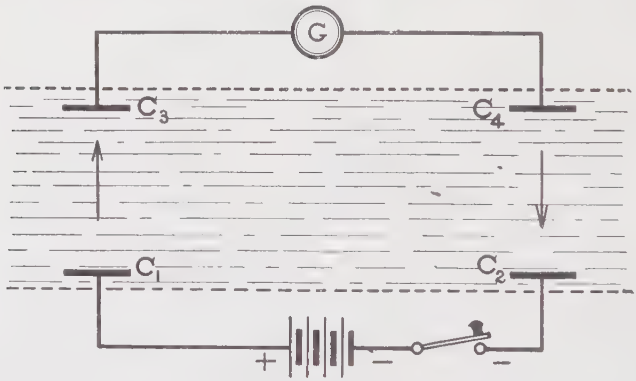


FIG. 219.

two immersed copper plates, C_3 and C_4. When the key was depressed the current flow was as shown by the arrows.

It is interesting to note that Morse considered the best effects were obtained when the length of the wire base along each shore should be three times the range from shore to shore; under present-day conditions the ratio of base to range is far different.

In 1882 Graham Bell adopted a suggestion made by Professor Trowbridge of Harvard University; this was to employ an

interrupted current at the transmitter and a telephone ear-piece at the receiver. His transmitter consisted of a battery of six Leclanché cells with an interrupter, and a 100 ft. base of insulated wire connected to the metal plates immersed in the river; the receiver base was also 100 feet between the immersed plates, and the greatest range recorded was one and a quarter miles through the water.

In the same year, 1882, an arrangement was patented by Prof. Dolbear in the United States by means of which speech communication was established over a range of more than half-a-mile. Dolbear's method is illustrated in Fig. 220. The transmitter

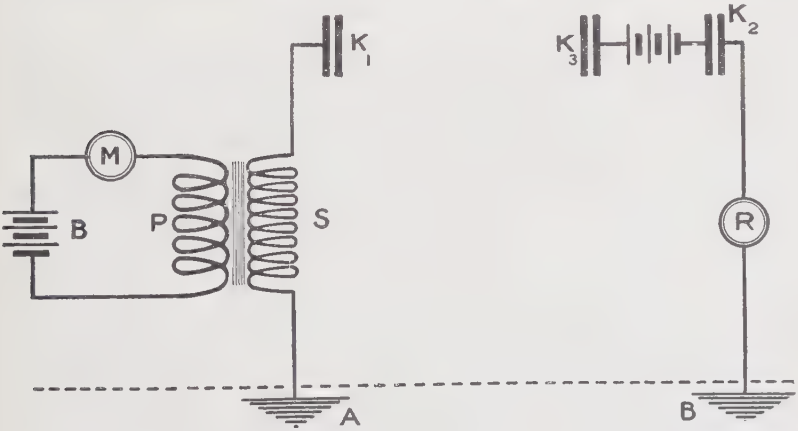


FIG. 220.

consisted of a microphone M, battery B, and induction coil PS. One end of the secondary of the induction coil was earthed, the other end was connected to a condenser K_1. Reception was made on a telephone receiver R connected at one terminal to earth, at the other to a condenser K_2, which was connected in series with a battery to a second condenser K_3 for reasons which are not evident. Speaking into the microphone M caused pulses of potential to be induced in the secondary coil S, and therefore in the ground at A. In consequence earth currents flowed, producing similar pulses of potential at B so that the speech was reproduced in the receiver R. Instead of the microphone Dolbear wrote also of using an interrupter and a Morse key in the primary, in other words an ordinary spark induction coil; no doubt with a large spark

induction coil, and a larger battery than could be used with a microphone, greater ranges could have been recorded.

Dolbear's method is interesting as it was a near approach to ether wave signalling, or wireless telegraphy, since the condensers K_1 and K_2 might consist of elevated wires or plates, but it will be seen that no attempt was made to generate and use high frequency oscillations. It was left to Hertz to demonstrate, in 1888, the possibilities of high frequency oscillations, of which Marconi soon developed the commercial advantages as a means of signalling.

Sir Wm. Preece, as Engineer-in-Chief to the British Post Office, carried on experiments in signalling by earth and water conduction for many years, using at the transmitter an alternating or interrupted current, and an ordinary telephone receiver in the reception circuit.

In 1898 he was able to establish a regular service over the 3·3 miles between Lavernock Point and Flatholm in the Bristol Channel. It is interesting to note that Preece supported his base lines on telegraph poles, at least in some of his experiments.

This range was disappointingly small for the amount of energy used, but the elements of the problem were at least understood; the apparatus and arrangements employed were paving the way for the subsequent welcome given to high frequency or ether wave methods, so that when Marconi arrived in England in 1896 Preece was at once interested in his work and gave him every encouragement.

The long ranges which were rapidly developed by ether wave methods stopped all serious experimental work on the methods of earth conduction, and it was only the necessities of modern warfare, in which ordinary lines and wireless aerials cannot be maintained under shell-fire, which re-opened the field for the immediate forerunner of ether wave signalling. Also the development of valve amplifiers has made it possible to attain ranges and results by earth current signalling which would have been quite unattainable before the war.

During the war valve relays, or amplifiers, have had two main applications when used for reception on earth bases; one for purposes of signalling from one point to another by methods similar to those already described, the other for purposes of intercepting messages from neighbouring lines. Interception work again is divided under two headings: first, the interception of messages

sent on the enemy's lines; second, the interception and checking of messages sent on our own. The first is to gain information from the enemy, the second to see if our own lines are at all faulty, and ensure that they will be repaired before the enemy gains information from them.

The initiation of earth signalling by the Allies during the course of the campaign was largely due to the work of the French Central Bureau de Telegraphie under Col. Ferrié, and this method has been called by them T.P.S. ("Telegraphie par le sol"). Transmission was carried out by means of a specially designed spark induction coil, which is called a "Power buzzer" in the Service, though in some cases a hand-driven alternator has been used. A 2 or 3 valve Low Frequency Amplifier was used in the Receiving base.

With a power buzzer of the "Parleur" type on a 10-volt battery and a 100-yards earth base between the plates, in a fairly dry type of soil over chalk, good signals have been obtained over a range of 5 kilometres, the receiver being a 3-valve L.F. Amplifier connected to two earth plates 200 yards apart. When the secondary of the Parleur delivers about 0·2 ampere into an earth base of 200 ohms resistance the primary will take about 2 amperes at 10 volts, or 20 watts of primary energy.

It is evident that the effect at the distant receiver is due either to the transmitter current spreading over the conducting surface soil, or to inductive effects causing magnetic strains in the ether in the soil, or to a combination of both. Let us first consider the case for conduction as against induction.

If the circuit of a battery or buzzer is completed by immersing two metal plates in a uniform conducting or semi-conducting medium, such as water, the current flowing from one plate to the other through the medium will spread out uniformly as shown dotted in Fig. 221. Considering any current path, such as ABD, there will be a uniform fall of potential in the medium from A to D, just as there is a uniform fall of potential in a uniform wire if a current flows along it. Thus there is a difference of potential between A and D; similarly there is a smaller difference of potential between M and N. If we connect plates to the receiving apparatus and immerse them in the conducting medium at M and N, a current will flow through this receiving circuit. The strength of the current will depend on the difference of potential (V) between M and N. Now by Ohm's Law $V = CR$; R is greater the greater the distance between M and N, but C

is less since most of the current will take the shorter paths shown dotted between the plates.

Along each path there is the same drop of potential, since each path represents a circuit and the same battery voltage is applied to all the circuits. Thus corresponding to the point A on the path ABD, there are points E, F, G, etc., on other current paths which have the same potential as A; if all these points are joined they will be found to lie on a circle whose centre is on the prolongation of the imaginary line connecting the immersed transmitter plates. This is called an equipotential circle, and any number of these can be drawn connecting points in the medium at equal potentials.

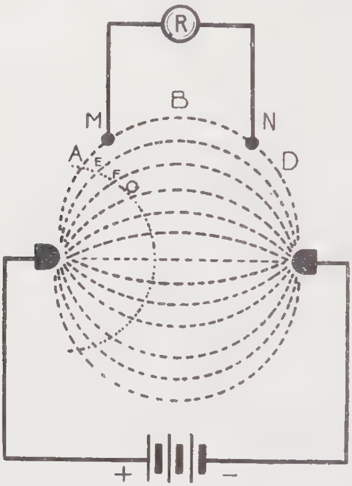


Fig. 221.

When the plates are buried or sunk in the ground these theoretical considerations can only be applied if the ground surface, and the substrata, are considered to be uniform in composition, and therefore in resistance. If this is assumed then the current paths are arcs of circles on the transmitting base as a common chord; equipotential points lie on circles the centres of which are in line with the transmitter base, and the circles which represent long ranges pass approximately through the centre of the base. (See Fig. 222.)

The equipotential circle which passes exactly through the centre of the base has an infinite radius, *i.e.* it is a line at right angles to the base.

If a receiving base is to be submitted to the greatest possible difference of potential its ends should lie on two equipotential circles which differ in potential as much as possible. For example, in Fig. 222 a receiving base placed at *ab*, or CD, or *ef*, would experience no difference of potential and theoretically would receive no signals. Thus the receiving base should be a normal to the equipotential circle on which the centre of the base lies; *i.e.* it should be in line with the radius of the circle passing through the centre of the receiving base. In Fig. 222 the base

mn is in such a position, its centre being on the equipotential circle A.

It is seen that the line joining the centres of the receiving and transmitting bases should be itself the base of an isosceles triangle, whose apex is the centre of the equipotential circle passing approximately through the centres of both bases.

If the receiver base is placed parallel to the transmitter base, as at OP, the base angles of the triangle are each 90° and the apex is at infinite distance.

It is theoretically possible to receive signals when the receiving

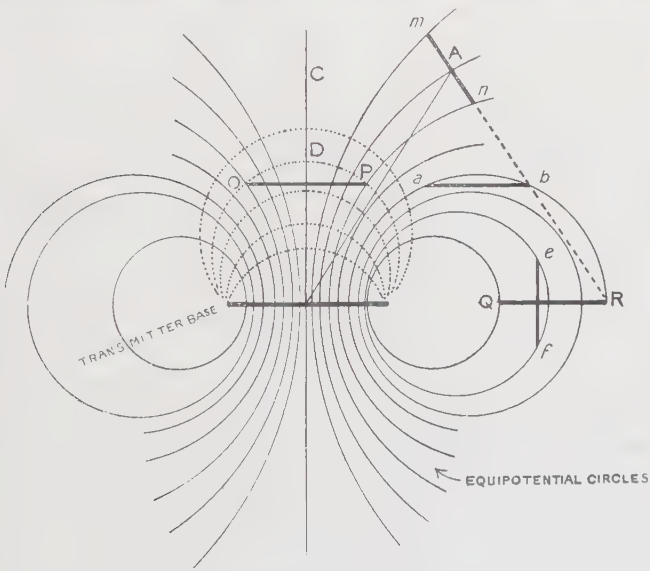


Fig. 222.

base is in line with the transmitting base, as at QR. In this direction the equipotential circles are far apart, therefore for such a case the receiving base would have to be very long, and one end of it fairly close to the near end of the transmitter base.

Now let us consider the arguments which prove it to be scarcely possible that the effects at the distant receiver are not explained by this simple conduction theory, and that they are probably due to induction.

(*a*) Referring to Fig. 221 it will be seen that the current spreads out on both sides of the transmitter base, therefore only

one half of the current put into the earth is operative towards one side. Taking the example given earlier in the chapter it is inconceivable that 100 milliamperes, from a 100 yards base, will spread sufficiently over 5 kilometres of dry surface soil to give readable signals, at that range, by tapping two points in the current path. In fact it can be proved theoretically that the potential difference between the two points 200 yards apart, at a range of 5 kilometres, would not be sufficient to give readable signals if calculated on the conduction theory alone.

(*b*) A great part of the drop of potential between the transmitter earth plates will occur at the contacts between the plates and the soil, where the current density is greatest, therefore the difference of potential of two points even 200 yards apart on a current path 5 kilometres away must necessarily be very small. It will be shown later that the earth resistance between the transmitter plates greatly depends on their area of surface.

(*c*) Alternating or pulsing currents give better effects than direct current. Experiments have been carried out which were based on the hope that signals could be transmitted by simply using a key and a direct current battery; these were connected in series with a tikker arrangement, to make the current intermittent and give a musical note at the receiver. The range obtained with this method was much inferior to that given when the same amount of primary energy was passed to earth through a buzzer transformer of the Parleur or other similar type. Now it is probable that alternating currents do not spread as far through the earth from the transmitter base as direct currents, therefore they do not give as great a difference of potential at the receiver base plates if calculated on the conduction theory.

(*d*) It is possible to receive signals when the receiving instrument is connected to a complete and insulated loop of wire laid on the ground instead of two earthed plates; conduction cannot enter into this case where the effect must be wholly inductive. True the range obtained by using a loop at the receiver is never as great as when an earth base is employed, but the difference between an insulated loop and an earth base can be easily explained on the inductive theory, as in a succeeding paragraph.

(*e*) It is possible to connect an earth base and a loop in series to the receiver and make the connections so that the effects of the base and loop are in opposition when the signals are almost entirely extinguished. In the loop the potential is out of phase with the current by 90°, whereas in the base the potential would

be in phase with the current if we considered only the effect of conduction. Thus a direct opposition of effects can only be explained by inductive action in both loop and base.

Now let us consider how the transmission of signals from one earth base to another can be explained as an induction effect. In a succeeding paragraph it will be shown that the best ranges are obtained over a comparatively thin layer of surface soil lying on a substrata of bad conductivity—such as chalk; in this case the current spreads over the surface and does not penetrate to any great depth. Referring to Fig. 223 the induction coil, its leads and earth plates, and a current path such as ABD, may be considered as a closed loop of current around which the ether is magnetically strained. The receiver, its leads and earth plates, together with a band of earth surface which embraces the current path ABD may be considered as another closed conducting path or loop.

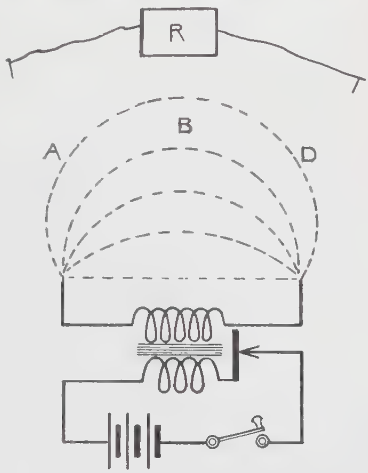


Fig. 223.

When the current alternates or pulsates in the transmitter loop the change of magnetic field, interlinking with the receiver loop, sets up potential effects in the latter by mutual induction. The receiver and transmitter closed circuits are coupled to each other by the earth surface which is common to both. Signals will therefore be received, unless the receiver is so far away that the magnetic strains round the outermost transmitter path of appreciable current do not induce potentials in the earth sufficiently near the receiver, or unless the resistance of the earth band between to the receiver earth plates is so great that the resulting currents are inappreciable.

The fact that the earth surface in this case is common to both the receiver and transmitter circuits, giving them a mutual induction coupling, explains why greater ranges can be obtained than when the receiver is connected to a loop of insulated wire; in the latter case the embrace of the wire loop is restricted by the convenient length of wire that may be used. If this were too great

it would be more convenient to have an ordinary wired-up system.

It is therefore very probable that in earth current signalling ether strains provide the method of propagation, as in the case of ordinary wireless telegraphy through the atmosphere; in earth current signalling energy is induced by the changing values of one kind of ether strain, in wireless telegraphy energy is radiated in the form of changing values of two kinds of ether strain acting at right angles to each other.

It is not possible to use high frequency currents and radiate energy through the earth, as it is radiated through the air in wireless telegraphy; the reasons for this have been dealt with in Volume I.

Transmitters for Earth Current Signalling.—The transmitter may consist of a special form of spark coil or power buzzer,

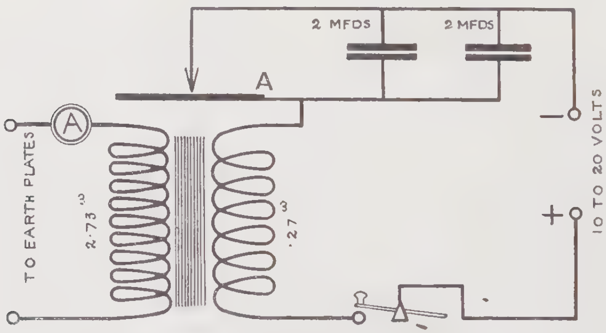


Fig. 224.

or it may be an alternator whose frequency is from 600 to 1000. One of the best known power buzzers is that which was used by the French Military Service during the war and called the Parleur.

It is a spark induction coil of special design, the theoretical diagram of its connections being as shown in Fig. 224. The primary is excited from a battery of 10 to 20 volts, and the secondary is attached through a hot-wire ammeter, A, to the earth plates or pins which are the extremities of the transmitting base. The make and break is shunted by two condensers, of 2 mfds. each, in parallel —a total of 4 mfds.

In order to obtain pulses of current at such a high frequency as 800 per second, and that this frequency will be kept constant without sticking of the vibrating interrupter, the Parleur, or other

power buzzer, must differ in design from ordinary spark induction coils.

The Parleur is shown in Fig. 225, and consists of a laminated iron core M on one leg of which the primary and secondary coils are wound, one over the other as shown. A laminated armature A nearly closes the gap between the poles of the core, the air space being not more than 0·25 mm. The armature is bolted to a strong steel blade S, to which is also attached a thin steel blade S_1 carrying at its extremity one platinum contact of the interrupter P. The

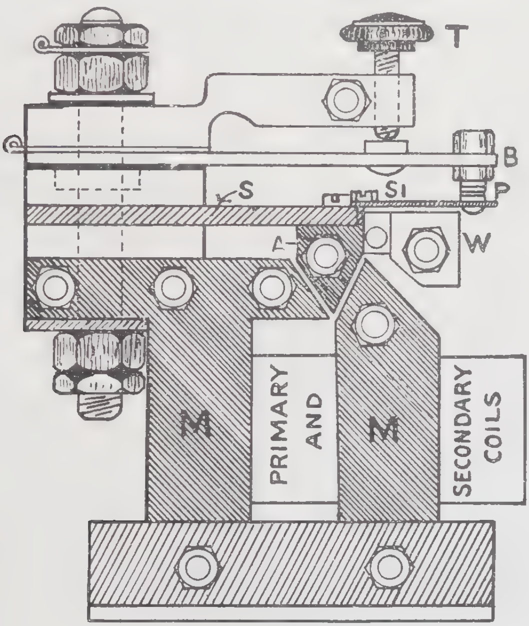


Fig. 225.

upper contact of the interrupter is carried on a brass arm B. A thumb screw T, carried on an upper brass arm, is used to adjust the contacts and vary the duration of interruption of the current; therefore, to some extent it can vary the frequency and resulting note. Brass weights can be dovetailed on to the steel arm S, as at W, so as to vary its period of vibration, and consequently vary the frequency and note within wide limits. The elasticity of the comparatively heavy steel arm, S, is such that the resulting frequency is practically independent of disturbing forces, especially that of

the thin spring arm S_1, which varies with the tension put on it by the adjusting screw. This stiffness of the vibrating arm S explains why a nearly closed magnetic circuit is adopted. At first sight it might appear difficult to use such a small interrupting gap for currents of 5 amperes or over without sparking; however, it must not be forgotten that the interruptions take place at a very rapid rate, and that a condenser of 4 mfds. can deal with currents higher than those likely to be employed.

The ratio of transformation of the Parleur is about 1 : 15; on 10 volts the primary takes about 2 amperes when the secondary is delivering 0·2 ampere to an earth base of 200 ohms resistance. As the resistance of the earth base decreases the current delivered to it by the secondary increases, and the input current to the primary increases; at the same time the efficiency decreases. The efficiency on a 150-ohm earth base is about 67 per cent. If the secondary is on an earth base of fairly low resistance, such as 50 ohms, and it is desired to put more energy into the transmitter the voltage applied to the primary may be raised to 15 or 20 volts; it will then be necessary to connect about $\frac{1}{2}$ ohm of resistance in series with the primary to avoid sparking at the contacts. On a high resistance earth base this extra resistance is not necessary.

Larger Parleurs have been made to handle 60 watts of primary energy, and have an efficiency of 55 per cent. on an earth base resistance of 100 ohms.

A small buzzer made by Messrs. S. G. Brown, London, is shown diagrammatically in Fig. 226; it can be made up in a case measuring 5 ins. × 3 ins. × 3 ins. including the key, and its note is very high and distinctive.

It will be noted that in this design of buzzer there is only one winding on the iron core, the earth current being due to the high voltage induced at the break of the interrupter which causes a discharge through the condenser and earth base.

A small buzzer of this design was connected to a 100-yards earth base, the earth being dry over chalk, and the base having a resistance of 488 ohms. The primary current was 0·095 ampere from the 30-volt battery and the earth base current was 35 milliamperes; a three-valve L.F. Amplifier was used for reception on an earth base 100 yards long. Signals were easily readable over 2000 yards, and were still readable though faint at 3000 yards.

During the war the German Army employed an instrument made by the Deutsche Telephonwerke, Berlin; it was a special form of buzzer with oscillating armature, so that an alternating

voltage is induced in the secondary winding and not a pulsating

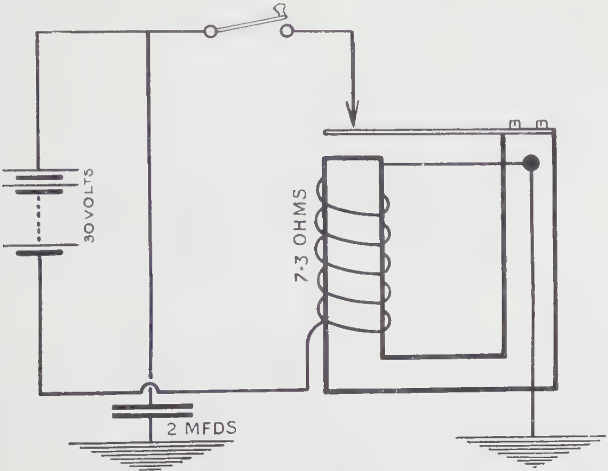


FIG. 226

voltage as in ordinary spark coils. The connections of this coil

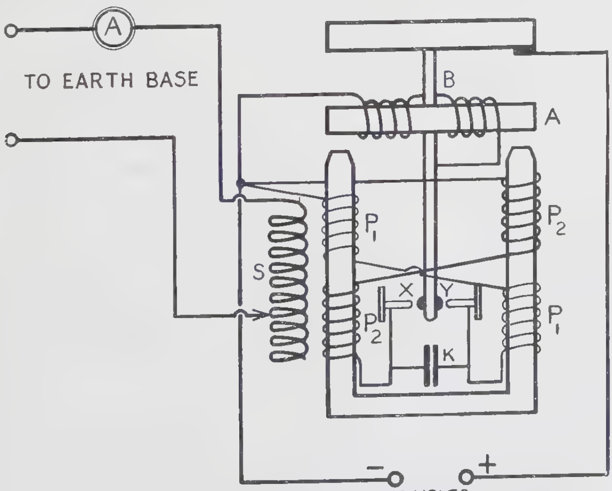


FIG. 227.

are shown in Fig. 227 ; it will be seen that the iron core is wound

with two sets of primary coils, P_1 and P_2, and the armature A is magnetised by a current from the battery flowing in a coil B which is connected in parallel with the primary coils. The armature has a fixed polarity while that of the core is reversed according as the lever arm (L) attached to the armature closes the contact through the primary at X or at Y. Thus the magnetism of the core is not simply established and then wiped out; it reverses with each reversal of the primary current, therefore an alternating voltage is induced in the secondary winding.

The secondary winding is wound over the primary on both limbs of the core and has four tappings on it: an ammeter is connected in series with it and the earth base.

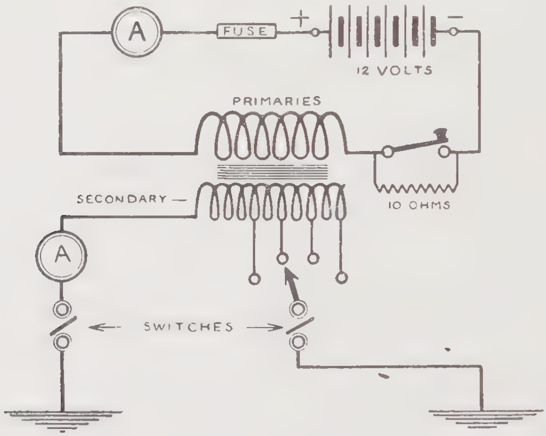


FIG. 228.

The tappings are provided on the secondary coil so that a suitable value of the induction in it may be chosen according to the earth resistance of the locality in which the instrument is used.

The actual transmitting connections of this instrument are shown diagrammatically in Fig. 228; it is seen that when the key is open the primary circuit is still completed through a resistance of 10 ohms which keeps the armature oscillating on a reduced current of about 3 amperes. On closing the key the resistance is shorted and the normal working current flows; this will be about 9 to 12 amperes, according to the resistance of the earth base to which the secondary is delivering energy. The key is

hinged, and when closed up out of action it breaks the primary circuit completely.

On test over a range of 4700 metres signals of strength R. 7 were received on a 3-valve amplifier from this power buzzer. The bases were parallel, that of the power buzzer being 150 yards long whilst the amplifier base was 150 yards long. Single bayonet earths were used at each contact, and under the same conditions the signals from a Parleur were of strength R. 5. The note of this German buzzer is very clear and can probably be read more easily through jamming than that of the Parleur.

Choice of Frequency.—While alternating current gives longer range of signalling than direct current it does not follow that the range will increase with the frequency of the alternations. As pointed out in Volume I. a high frequency current does not penetrate to any great depth into the earth, and the penetration will be less the less the resistance of the soil. Experiments have proved that high frequency currents put into a transmitter base do not spread very far. Brylinski has shown that a current whose frequency is a million cycles per second will not penetrate much more than 6 metres into the earth, nor more than 1·5 metres into sea water. It is not possible to radiate wave energy in the ether in the earth, since the energy of wave strain is quickly turned into current energy. If we come to consider alternating current of acoustic frequencies, which will give a note in the receiver telephones, although we might expect that the induced E.M.F. in the receiver circuit would increase with the frequency, experiment has shown that the increase, if anything, is very small. The author has tested a buzzer, similar in design to the Brown buzzer previously described, with a note frequency of 2500 to 3000 per second. The buzzer took about 0·2 ampere on 30 volts and had an efficiency of about 77 per cent. on an earth base of 250 ohms resistance. When the transmitter and receiver earth bases were 100 and 200 yards long respectively the extreme range of signalling was only 2000 yards over favourable earth surface.

An apparent advantage of a high-note buzzer is that the note is distinctive and can be read through interfering noises caused by atmospherics or leaky electric lines in the neighbourhood. For maximum range of signalling the frequency must not be too high, and the efficient value is really determined by conditions at the receiver end. That is to say, in practice, the range will generally be a maximum if the resulting note is that on which the telephone receivers are most sensitive, or the ear most sensitive, all other

conditions being equal. Both these considerations point to a frequency of 600 to 800 per second as being the most efficient. It may be important to arrange so that the frequency can be varied, by adjustment at the interrupter of the buzzer, in order that the note of one buzzer can be read through the interference of another.

Effect of Geological Conditions.—The range of signalling will depend upon the nature and condition of the surface strata and of the substrata immediately underneath it. A good conducting soil is not the best to signal through, whether viewed from the conduction or induction standpoint; for example, a thick, damp, loamy soil will not give long ranges because its conductivity is so good that the current between the transmitter earth plates does not spread to any extent.

In the author's experience the longest ranges were recorded over country where there were no fences nor intervening roads, and where the surface consisted of a light soil of comparatively thin layer on a chalk substrata. Here the surface soil acted as a conducting plate of fairly high resistance over which the spread of the current between the transmitter plates was considerable; the chalk, of very high resistance, acted as an insulator to prevent a great component of the current from penetrating downwards instead of outwards. Under such conditions ranges of 5 and 6 kilometres were quite usual between a 20-watt Parleur power buzzer and a 3-valve amplifier receiver. Not much difference was noted in the strength of the signals whether the soil was dry or moderately damp. When it was dry the current spread more, when it was damp the drop of potential at the earth plates was reduced, accompanied by an increase of both earth current and primary energy.

Screening Effects.—If a river or stream intervenes between the transmitter and receiver bases the range will probably be considerably reduced, as the water forms a good conducting path; the current will not spread beyond it but will take the path of least resistance through the water, hence for inductive or conductive coupling the receiver and transmitter must be placed closer together. This is analogous to the distortion caused in the uniform field round a magnet when a piece of good conductivity iron is placed near and alongside it; there will be no magnetic lines of strain in the ether beyond the iron. The same effect may be caused by iron or wire fencing on iron supports between the transmitter and receiver.

An intervening railway, road, or street may also give serious screening effect, because they are generally made by cutting away

the earth and, on the substrata, building them with stones or sand or other hard material of high resistance. The spreading current from the transmitter cannot cross this barrier so that there will be no inductive coupling if the receiver base is too far away. An intervening exposed outcrop of substrata such as limestone or chalk may have the same effect. During the campaign in France great difficulty was experienced in signalling by earth currents in the Artois country after the surface had been badly cut up by shell-fire. The surface soil was a light layer over chalk and the shelling broke up this surface, mixing it with chalk or exposing the latter, so that the current could not be spread over it on account of the high resistance. In the Ypres salient earth current signalling was also always very difficult, the reason in this case was that the surface strata is thick, always more or less damp, and lies on a substrata permeated with water.

Length of Earth Bases.—If the transmitting base is kept constant and the receiving base is increased in length from zero it is evident that the mutual induction coupling will increase up to a maximum; beyond this further increase of the receiver base will not increase the coupling, but will unnecessarily increase the resistance of the receiver loop.

Similarly, if the receiver base is kept constant in length while that of the transmitter is increased from zero the mutual induction will increase, but at the same time the transmitter current will diminish owing to the increasing resistance of the earth base. For small ranges up to 2000 metres it is found that for a given strength of received signal the length of transmitter base multiplied by the base current should be a constant. For longer ranges it is difficult to find an approximate formula since so many effects, such as conduction, induction, geological and screening conditions, enter into the results. One can only say that the shorter the transmitter base the more current required in it, and that great length of receiver base does not lead to efficiency or increased strength of signals. The length of the receiver base should theoretically increase as the range in increased.

On a light soil over chalk the author has worked consistently over a range of 4 to 5 kilometres, using transmitter and receiver bases each 100 yards long, a 20-watt Parleur buzzer, and a 3-valve L.F. receiving Amplifier. The buzzer and the amplifier can be installed anywhere in the respective earth bases; thus they may be connected near one earth plate so that there is only one long earth lead away from each instrument.

Good signals have been obtained over 4000 yards with a buzzer base of 50 yards and a receiver base of 100 yards. Given a buzzer output of 20 watts nothing will be gained by making the receiver base more than 300 yards long.

Earth Base Leads.—The cable connecting the earth plates to the transmitter should be of good cross-section and good conductivity copper, for it is desirable to have as much potential drop as possible in the earth and as little as possible in the leads. Cable with a steel or iron wire strand is not suitable. The cable should be well insulated. For the receiver base finer wire may be used as the receiver currents are so small, but naturally this remark does not apply to two-way working. The earth leads may be buried provided they are well insulated and that the insulation will not deteriorate.

Direction of Earth Bases.—If the reception of signals is considered as a conduction effect only it has been shown, in connection with Fig. 222, that the best direction of bases is such that they make equal angles with the line joining their centres. Since, however, the inductive effect is probably more important than the conductive one, it is necessary to consider the problem from an inductive point of view. Let the line connecting the centres of the receiving base and the transmitting base make an angle θ with the latter; the direction of the resultant magnetic field at the receiving base will make an angle ψ with this line such that $\tan \psi = \frac{1}{2} \cot \theta$. The receiving base should be placed at right angles to the resultant magnetic field, therefore it makes an angle θ' with the line joining the base centres such that $\tan \theta' = \cot \psi = 2 \tan \theta$.

Therefore this condition gives the best direction of the bases. If the line joining the centres makes a right angle with the transmitter base then θ is 90° and θ' should be also 90°; in other words the bases should be parallel to each other.

Earth Plates or Contacts.—Any clean metallic conductor driven into the surface soil is suitable for connecting the transmitter and receiver to their respective earth bases. It must be remembered that the current which will flow into the earth, from the secondary of the power buzzer, depends not only on the resistance of the earth base but also on the resistance between the earth plates and the earth; to keep this resistance low it is always advisable to use several contacts in parallel with each other rather than one contact at each end of the base. A low resistance between the earth plate and the earth reduces the serious drop of potential which occurs at this point.

Steel pins or bayonets make suitable earth contacts ; at least three of these should be connected together by copper wire and driven into the ground not less than 2 feet apart, the line of pins or bayonets being at right angles to the earth base. If the earth pins, or plates, in a group are not kept apart the current flow from one will interfere with that from the others, and so increase the effective resistance. It follows that when an earth connection consists of a number of plates in parallel their proper distance apart will depend directly on the size of the plates, also on the amount of current flowing into the earth base.

If circumstances permit it is advisable to select wet spots for the earths, and improve them by burying other earths, such as biscuit tins or copper plates. Watering the earth around the contacts with a solution of common salt will improve them greatly ; packing damp charcoal round the earth plates has also been found to improve the contacts.

If bayonets or standard earth pins are not available suitable earth contacts can be made by burying :—

(1) Biscuit or petrol tins with bare copper leads threaded through holes or soldered to the tins.
(2) Shell cases with copper leads soldered on.
(3) Earth pipes well watered.
(4) Wire netting well covered up and trodden in.

At the transmitter end it will not do to put both earths in the same wet ditch or stream ; if this were done the current would flow along the stream or wet ground, from one set of contacts to the other, without spreading. Thus, although the resistance is low and the current from the buzzer may be considerable, no current is spreading out towards the place where the receiver base is installed, hence no signals are received.

If a wire fence, or a stream, is running in the direction from the transmitter to the receiver one of the terminals of the transmitter can be connected to it. If it is possible, at the same time, to connect one of the terminals of the receiver to the fence or stream, the range will be greatly increased.

Experiments have been carried out to find the resistance between various types of earth contacts on an earth base 100 yards long. At the time the experiments were made the ground was damp and four inches of snow lay on it. The measurements of resistance were made by a Bridge megger and by a battery and milliammeter.

The results were as follows:—

Nature of each earth contact.	Resistance in ohms. By milliammeter.	By megger.	Average.
(*a*) One bayonet in fairly damp ground	444	469	456
(*b*) Two bayonets 1 yard apart	260	264	262
(*c*) Three bayonets 1 yard apart	190	184	187
(*d*) One earth mat buried 4 ins. deep in very damp ground. Size of mat, $2\frac{1}{2}$ ft. by 2 ft.	89·7	88	89
(*e*) One 4-gal. petrol tin buried in fairly damp soil	318	347	333
(*f*) As in (*e*) but with very damp ground	235	257	246
(*g*) One bayonet in ground much wetter than that used in (*a*)	$\left.\begin{matrix}417\\444\\488\end{matrix}\right\}450$	$\left.\begin{matrix}435\\469\\474\end{matrix}\right\}460$	455

It is essential that the two systems of earth pins or plates used on a receiver base should be of the same material, otherwise they will form with the earth salts a galvanic cell and currents will flow through the receiver. If these were steady currents no sounds would be heard in the telephones, but it is more than likely that they will be intermittent or variable in value.

Power Buzzer Efficiency.—The ratio of the energy put into the power buzzer from the battery and the energy delivered by it to the earth measures its efficiency. Since interrupted currents are being dealt with they will be measured by hot-wire ammeters, connected in series in the battery and earth base circuits respectively.

A well-designed power buzzer on an average earth base should have an efficiency of about 70 per cent., but the efficiency will depend upon the resistance of the earth base.

Alternators for Use on Earth Bases.—A hand-driven alternator supplies the best alternative to the power buzzer, and one of the most successful for field work is the Dynalterna, type T.P.S., brought out by the French Military Authorities.

The revolving field consists of a single excitation coil wound on a solid iron core with 12 poles bent over to partly embrace the coil. This arrangement is similar to that in the old Morday alternator. The exciting current is provided through a commutator and brushes from four of the armature coils, the remaining eight armature coils being connected in two sets of four in parallel, so that when the machine is driven at a speed of 5000 r.p.m. 100 volts

are induced at the terminals on the open circuit, and at a speed of 8000 r.p.m. the open circuit voltage is 160; this is the maximum safe speed of the machine. The driving from the handle is done through gearing with a ratio of 1 to 130.

The machine may be short-circuited without risk of damaging it, since the short-circuit current will only rise to about 5 amperes for all frequencies; at this current its magnetic field is reduced to a minimum.

The armature has a resistance of 0·6 ohm, the excitation coil on the rotating field a resistance of 3 to 3·5 ohms, while the four pole coils in series which provide the exciting current have a resistance of 3 to 3·5 ohms.

A small board is supplied with the machine on which is mounted the manipulating key and a small reactance shunt with five tappings; these are marked Maximum, Strong, Medium, Average, and Feeble

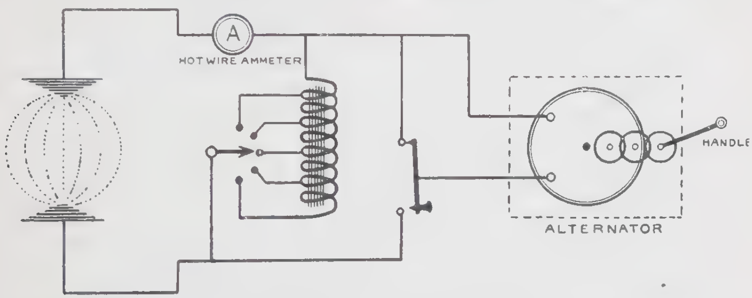


Fig. 229.

respectively. This reactance shunt consists of a coil wound on an iron core, and is connected across the alternator terminals, so that a certain part of the alternator current flows through it, and being an inductive load there is no energy loss, as this current is 90° out of phase with the volts.

For any given load (earth) resistance there will be a proper adjustment of this reactance shunt which will ensure maximum current going to the load, so that energy delivered to the load is from 30 to 60 watts, depending on the load resistance.

When open the manipulating key short-circuits the armature; this causes almost complete leakage of the magnetic field which is cut down to a minimum since there is now little induction in the four coils which provide the exciting current, hence little excitation.

The connections are as shown in Fig. 229, whilst its power, current, and voltage curves are shown in Fig. 230.

When tested as a power buzzer on a 100-yards earth base to a 3-valve amplifier on a similar base, good signals of strength R. 7 9 were received over a range of 4000 yards. The earth base resistance was about 300 ohms, and for this the best adjustment of the reactance shunt was found to be on the stud marked "Très Fort" (Maximum). The current flowing to earth was 400 to 450 milliamperes at a frequency of about 500, *i.e.* 50 turns of the handle per minute. The note received is clear and high, but a man can hardly maintain this speed on the handle for more than two minutes at a time.

The Germans also used generators, and one captured from them

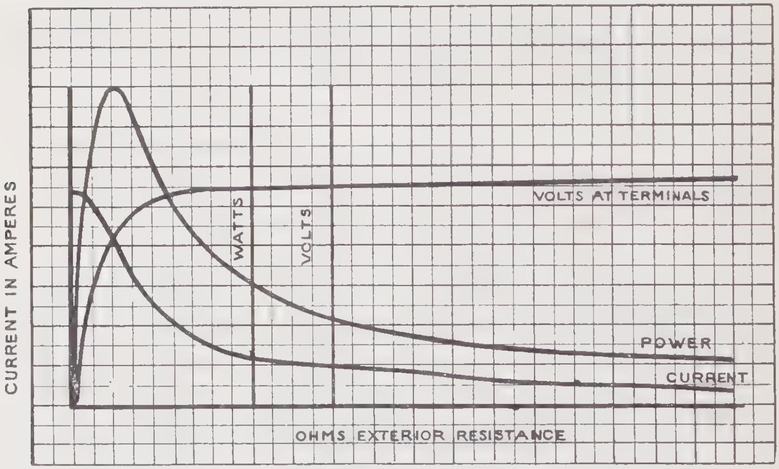


Fig. 230.

in a dug-out during the Vimy Ridge Battle was driven by foot from a tandem bicycle gearing—the bicycle frame being supported on feet let into a concrete bed in the floor of the dug-out.

The machine was designed for a frequency of 534; it was of the revolving pole type, the pole system being similar to that of the French hand generator as described above—but the German machine is a 16-pole one. The stationary armature consists of 16 coils wound in slots in a laminated iron core, while the exciting current is provided by a little D.C. machine, mounted on an extension of the shaft—this has two poles, one pair of brushes and a 20-part commutator. A field rheostat is mounted in the base of the machine, and the A.C. and D.C. terminals are in a

covered chamber on the base, from which armoured cable leads to plug connectors.

To generate at a frequency of 534 the machine would have to be driven at a speed of 4005 r.p.m., but on trial it was found difficult to maintain, by a man pedalling, at a greater speed than 2500 r.p.m., at which speed the machine generates 80 volts on open circuit. The connections of this machine are shown in Fig. 231.

It will be noted that terminals are provided on the D.C. exciter, so that a supply of direct current can be obtained for external

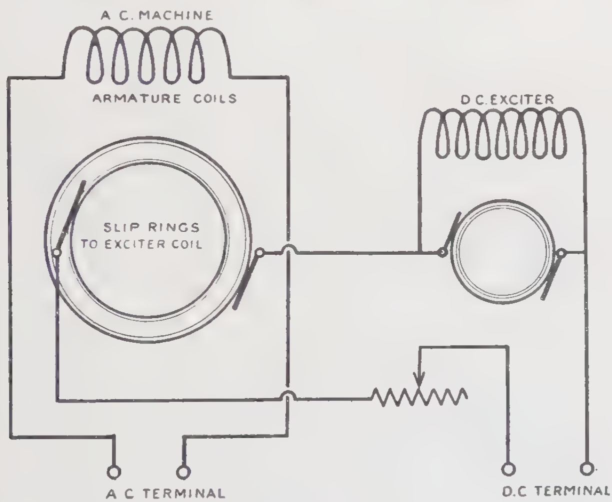


Fig. 231.

purposes; probably used for lamp signalling at 6 to 8 volts. The D.C. terminals would require to be shorted when the machine is used to excite the alternator.

Two or more Power Buzzers Working to the same Receiver.—If it is desired to have two or more power buzzers working to the same receiver several earth bases should be established in different directions at the receiver, and a commutator employed to bring into use, at any time, the base which gives the strongest signals. This is diagrammatically shown in Fig. 232, where three power buzzers work back to a receiver R; one terminal of the receiver is connected to earth, the other is connected to a multiple switch so that any of the bases 1, 2, or 3 can be used at will. Thus

if P.B. 3 is transmitting it should be received strongest on base 3. which is either roughly parallel to the base of P.B 3, or follows the general rule that the transmitter and receiver bases should make equal angles with the lines joining their centres. Owing to inequalities and screening effects in the earth conditions distortion will probably occur, hence in this case it would be wise to put out in different directions more than three bases at the receiver, with a switch containing the necessary number of contacts; the base on which the strongest signals are received can then be found by trial.

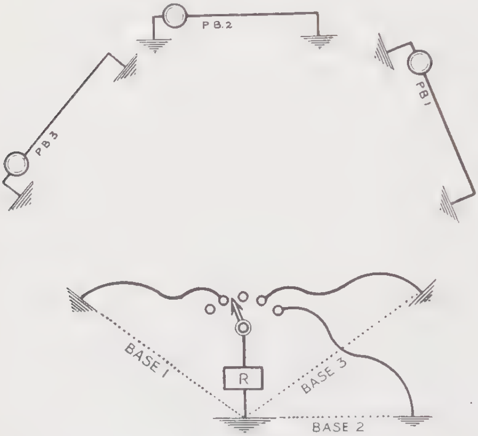


FIG. 232.

Reception from Power Buzzer.—As pointed out at the beginning of the chapter a pair of telephone receivers connected to the receiver base can be employed for receiving the signals; the range will then depend upon the delicacy of the receivers. Thus in an experiment, where a 10-volt Parleur on a 100-yards base was employed as a transmitter, and a pair of Brown receivers on a 100-yards base was used as a receiver, good readable signals were obtained over a range of 1000 yards. The earth contacts in each case were three bayonets connected to the instruments by copper cable; the receivers were two 60-ohm Brown ear-pieces in series. The ground was light sand overstrata on chalk, and the day was very wet and stormy.

Instead of putting the telephone receivers directly in the base they can be connected to it through one or more delicate relays in cascade; this will increase the range of signalling.

The Telefunken Company have for years employed microphonic relays in their wireless circuits which would be suitable for this class of work; in principle they are not different from the Brown relay and the Kramer relay, so that a brief description of one of these will suffice.

The Kramer relay, like the Brown and Telefunken, is one which can be made to respond strongly to a small range of

frequencies and be insensitive to other frequencies. It consists of a telephone receiver circuit, but the diaphragm is replaced by a fairly thick steel reed of a definite pitch (between 700 and 800 vibrations per second). The vibrations of this reed shakes microphonic contacts in a local circuit containing a battery and telephone receiver. When the incoming current has a frequency close to the resonance frequency of the relay reed the vibrations of the latter are a maximum. Its disturbance of the microphonic contact resistance is then a maximum, and therefore strongest equivalent pulses of current are set up in the local circuit.

Telefunken relays of this pattern have been described in Vol. I., Chap. XXI. It is easy to realise that with two such relays in cascade the effects produced by pulses of current not of the same frequency as the relay reeds will be very small, at least when compared with those produced by pulses in resonance with the reeds. The Telefunken Co. claim that two such relays in cascade will sort out two different notes in the same circuit when they differ in pitch by a minimum of 20 per cent.

Therefore such a system not only ensures longer ranges of signalling but it also cuts down very appreciably the jamming which might be caused by other buzzers of different note pitch in the neighbourhood.

Tuning out, or Limiting Interference Effects.—Experiments which have been made to tune the receiver base circuit of a valve amplifier to one buzzer note, and cut out others, have not met with much success. One method was to include in the base leads an inductance and variable condenser in series; this only reduced the strength of signals and gave no note tuning. If the condenser is connected in parallel with the inductance, or with the inductance and amplifier in series, the disturbing note can not be tuned out, and signals are reduced in strength. One difficulty encountered when trying to tune out a disturbing note is that it is generally rich in harmonics which makes complete tuning out very difficult.

A method of tuning which gave positive results, without, however, eliminating the jamming of another buzzer, is shown in Fig. 233. A simpler method would be to connect an inductance and capacity in parallel with each other and shunted across the telephone receivers on the amplifier. The capacity should be of the order of 1 microfarad, the inductance of such a value as to give note resonance and with as low resistance as possible. As a matter of fact any of these methods will probably weaken the looked

for signals, since they tend to wipe out the harmonics which make the buzzer note distinctive.

Where the interference is caused by leaky telephone or electrical lighting circuits a simple combination of earth bases at the receiver

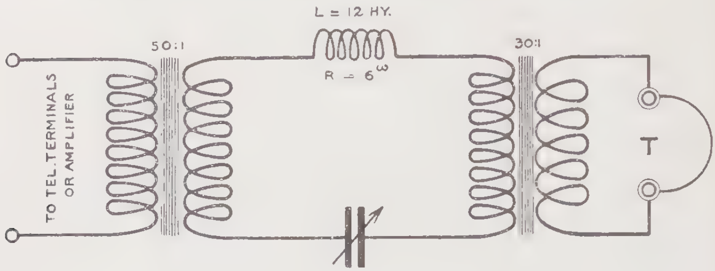


Fig. 233.

may be effective. Thus, referring to Fig. 234, let AB be the working base and suppose that noises are set up by a leak from an electrical circuit in the neighbourhood. Another earth base is put out at CD and connected to the second primary on the transformer. Assuming the bases to be so placed that the disturbing effect will influence both equally the primaries of the transformers can be connected to the bases in such a way that the results annul each other. Since, however, the currents from the transmitting station will act on AB more than on CD the signals will come through practically unimpaired.

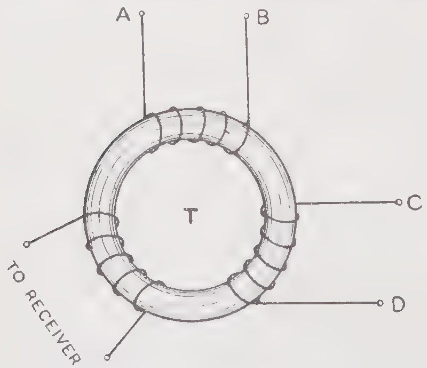


Fig. 234.

Instead of having only one earth base at CD a number of earth plates can be installed in different positions and connected up through a multiple switch, so that any pair may be chosen which will best reduce the interference or least reduce the strength of signals. It is seen that this method is also effective for reducing noises in the amplifier caused by earth currents, or atmospherics.

Signalling with Inaudible Frequencies.—It is possible to make

a valve oscillate at a low or audible frequency and so make it act as a power buzzer; one method of doing this is shown in Fig. 235. In the arrangement shown A and B were ordinary Marconi telephone transformers and the valve was an ordinary French receiving valve. Good signals were obtained over a range of 1500 yards. More power could be obtained by using higher voltages, or larger valves, or connecting valves in parallel.

An interesting arrangement would be to make the valve oscillate just above audible frequency and tune the receiver circuits so that the receiver valves oscillate at a slightly different frequency thus giving reception by the formation of beats. With this method the communication could be kept secret as it would

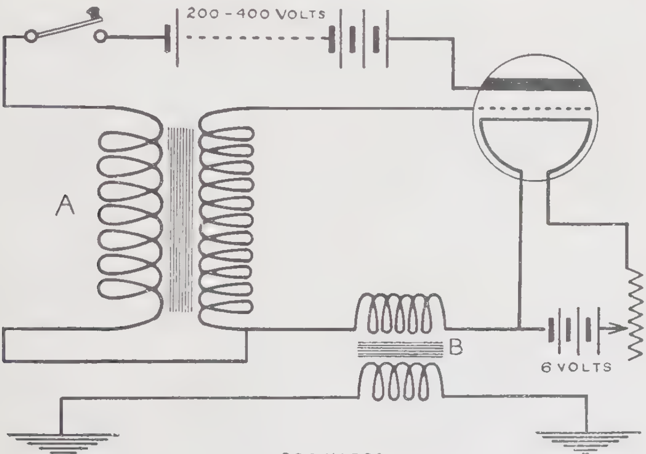


FIG. 235.

only be received on a properly tuned circuit; however, as remarked before, earth current signalling at these comparatively high frequencies is only possible over short ranges.

Earth Current Telephony.—A microphone current can be stepped up through a valve amplifier and then applied to an earth base as a telephone transmitter. An ordinary low resistance microphone is connected in series with a battery of 3 or 4 volts to the low resistance primary of a small transformer, the secondary of which is connected to the grid and filament of the first valve in a 3-valve amplifier. To get good amplification of the microphone or speech current it will be necessary to use a fairly high plate

potential of 200 or 300 volts; this may necessitate the use of two or more valves in parallel at the second and third stages of the amplification. The transformer in series with the last plate circuit should be a step-down one whose secondary has a resistance approximately equal to that of the earth base it is proposed to use, and to which the secondary is connected. Reception takes place on a valve amplifier in the ordinary way. With bases 100 yards long it is possible to carry on communication in this way over a range of 1500 yards.

QUESTIONS ON CHAPTER XVII.

1. Briefly state the reasons why signalling by earth currents must be mainly an inductive phenomenon.

2 Why is it not possible to use high frequency currents to signal through the earth as well as through the air?

3. How is the range of earth current signalling affected by—
   (*a*) The power of the transmitter;
   (*b*) The geological conditions of the earth over which signalling takes place;
   (*c*) The length of the transmitter base;
   (*d*) The length of the receiver base?

4. What difficulties are likely to be encountered in establishing communication between two places by earth current signalling?

CHAPTER XVIII

MISCELLANEOUS VALVE APPARATUS AND APPLICATIONS

Valve Wavemeter.—A valve wavemeter consists simply of an oscillating valve circuit which may be made up as shown in Fig. 236 (A) or (B). In Fig. 236 (A) the telephone receivers are

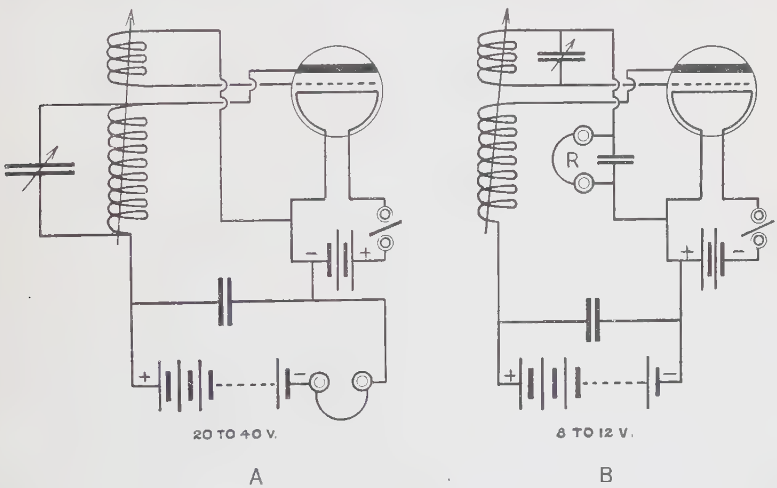


Fig. 236.

connected in series in the plate circuit and a blocking condenser is shunted across them and the plate battery; with this connection it will be found that from 20 to 40 volts are required in the plate circuit to make the valve oscillate, presuming it to be of the usual French valve type.

In Fig. 236 (B) the telephone receivers are shunted across a small condenser in the grid circuit and thus act as a leaky resistance across this condenser. With this arrangement it will be found that the valve oscillates on 8 to 12 volts in the

plate circuit but will not oscillate if the telephone receivers are disconnected.

In either case the coils, of No. 28 or 30 S.W.G. silk-covered wire, can be made of the flat spiral design placed close to each other, thus giving close coupling and taking up little room. They should be rigidly fixed, as a change of coupling will change the inductance effect and so upset the calibration of the meter. A favourite method is to mount them in a block of ebonite which is filled up with paraffin wax before an ebonite cover is screwed on. The connecting wires in the instrument should be stiff to avoid changes of inductance or capacity effects: too much care cannot be taken in this respect, especially when dealing with C.W. signals.

The tuning condenser should not have a high maximum value; about 0·0005 mfd. is a suitable value, as it gives fineness of tuning and does not overload the weakly oscillating circuit with capacity effect. The fineness of tuning will make it possible to distinguish clearly the silent point when the meter is held near to, and heterodynes, another valve system.

Great ranges of wave length should be obtained by having interchangeable sets of coils rather than by having a large range on the condenser for reasons given above; when a range of longer wave lengths is to be measured the grid circuit coil should be given a greater inductance value at the same time as the plate circuit coil.

In tuning a transmitter the valve wavemeter should be held near the aerial and not near the transmitter itself; the farther it is held from either the better, because mutual induction effects between the wavemeter and the transmitter circuit may cause an error of several metres wave length to be registered. It should be possible to note the wave length when the wavemeter is held several yards from a transmitting aerial. It is equally important to keep the wavemeter as far away as possible from a valve receiver when tuning the latter.

As a matter of fact a valve wavemeter, though very convenient, can never be accurate since the capacity effect of the valve itself enters into the values obtained on calibration, and this capacity effect is not uniform, even in valves of the same design. Also a variable condenser is not a portable apparatus unless very rigidly constructed, and a slight change of its capacity will make a considerable difference in the wave length when it is employed as a shunt across a coil.

A better type of wavemeter is the buzzer one described in Vol. I., where the tuning is done by a variometer, and reception tuning noted by means of a small lamp with heated filament, by a galvanometer, or by a neon tube; this type is shown in Fig. 237. A valve wavemeter is useful for noting harmonics, and it is possible that one in which a valve of small capacity is employed, such as a Marconi Q valve, will usefully serve as a portable instrument for ordinary measurements and comparisons.

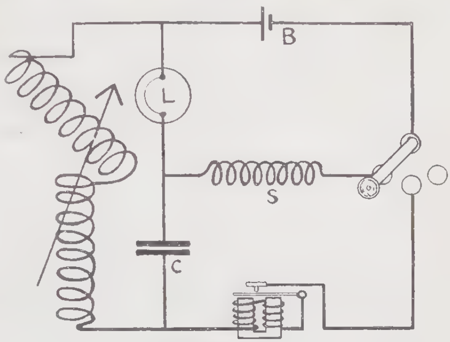


FIG. 237.

Wavemeters for C.W. purposes must be very carefully calibrated, especially when many stations have to work in close proximity on wave lengths differing only by a small percentage. The best method of calibration is to tune a Multivibrateur (already described in Chap. IX.) by means of a standard tuning fork, and calibrate the wavemeter on its harmonics.

Use of a Valve for Eliminating Jamming.—It has been shown in Chap. V. that if a valve is feebly oscillating, at a certain frequency on a receiver circuit, it provides an E.M.F. which just neutralises the ohmic drop in the resistance of the circuit for oscillations of that frequency. This is sometimes known as the "negative resistance" effect of the oscillating valve; it has been applied in a patent taken out by Pupin and Armstrong for the elimination of jamming, especially by strays.

The method adopted is shown in Fig. 238; the plate and grid circuit of the valve are both coupled to the aerial circuit and through it to each other, the couplings being adjusted so that the valve generates oscillations. The aerial and grid circuits are tuned to the frequency of the ether waves it is desired to receive, the grid potential being adjusted by means of a battery or potentiometer.

When the valve oscillates it wipes out the effect of resistance in the aerial circuit, even when this resistance is of high value, so that the amplitude of oscillations induced in the aerial by ether waves of the given frequency will be greater than would otherwise be the case. The negative resistance effect will not exist for waves

of a different frequency, or length, and in order to prevent more effectually the latter from inducing oscillations in the aerial a comparatively high resistance r_1 is included in it. A high resistance r_2 is connected across the portion of the aerial circuit in which the negative resistance effect is introduced; this enhances the

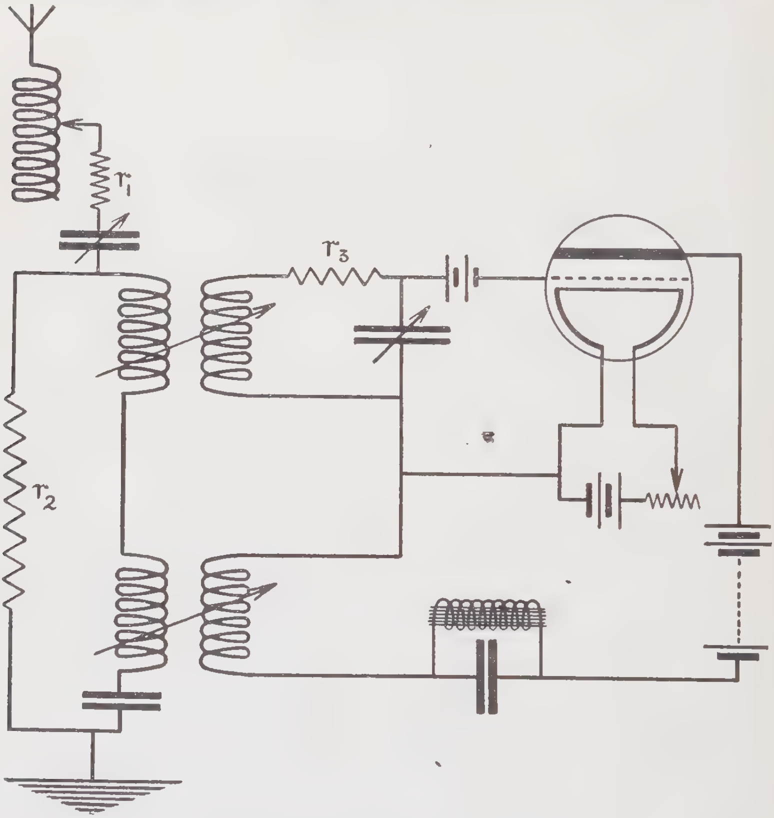


Fig. 238.

latter effect. The resistance of two resistances in parallel is their product divided by their sum; if therefore $-R_1$ be the negative resistance effect the combined resistance of r_2 and $-R_1$:

$$R = \frac{r_2 \times (-R_1)}{r_2 + (-R_1)} = \frac{-R_1 r_2}{r_2 - R_1}$$

If r_2 is greater than R_1 then $r_2 - R_1$ can be made very small, and R will then be approximately equal to $-R_1 r_2$, which is a greater

negative value than $-R_1$. To take an example, suppose the negative resistance $-R_1$ is 90 ohms; if it is shunted by 100 ohms the combined resistance is $\frac{90 \times 100}{100 - 90} = \frac{-9000}{10} = 900$ so that the effect is increased 10 times. It is therefore possible to include a high resistance r_1 in the aerial and yet wipe it out for oscillations at the valve frequency. This high resistance will damp down oscillations of other frequency and reduce the effect of strays. The resistance r_3 is inserted in the tuned circuit of the valve in order to adjust the time during which resistance compensation is completed by the valve oscillations. An atmospheric or stray may set up oscillations by shock in the aerial, at the frequency to which the latter and the valve are tuned, but these will die out before the resistance compensation is complete; a persistent received oscillation at the given frequency will gain the full effect of the compensation.

The receiver circuit can be coupled to the aerial circuit in the usual manner, or valves in cascade can be arranged.

For example, the grid circuit of a first valve can be coupled to the aerial and its plate coupled through a tuned circuit to the grid circuit of a second valve. The plate circuit of the second valve can then be coupled back to the aerial, and with this arrangement greater selectivity is obtained.

Valve Amplifiers in Telephone Lines.—It is apparent that valves may be employed for relaying or amplifying up weak telephone pulses in a line, in fact great development in this direction may be anticipated now that the hard valve has been perfected and is so uniform in its action. The simplest method of valve relaying would be to connect the lines through a transformer to the grid circuit of a valve, the telephone receivers being connected in the plate circuit. This would be a costly method since it implies one valve outfit at each instrument; except in rare cases it would not be feasible since the valve relays would be installed in places where they would not be under the control of experts, and any fault in the valve circuits would stop communication altogether. Therefore it is better to make the valve amplify the pulses in the main line, installing it for preference in a relaying station near the centre of the line so that its amplifying effects will be equal for speech in both directions. If the relay station is not near the electrical centre of the line it is still possible to get equal amplification in both directions by using an artificial line for balancing purposes.

Thus, on a single main line, the valve amplifier or relay may be connected as shown diagrammatically in Fig. 239; the main line passes through a transformer or repeating coil at R, and the secondary of R is connected to the primary of a transformer T_1 which has four windings on one core. Pulses of current in the lines induce, through R, pulses of current in the coil 1 2. These induce pulses of potential in the coil 7 8; these act on the grid of the valve inducing pulses of the local current in its plate circuit. These set up induction in the secondary of the transformer T_2 and

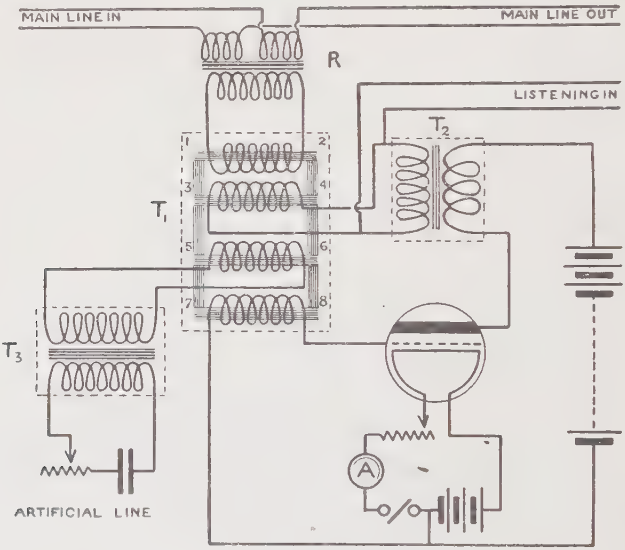


Fig. 239.

therefore pulses of current in the coil 3 4 of T_1. Through the coil 1 2 and R these pulses induce corresponding ones in the line which are in synchronism with the original line pulses and therefore strengthen the latter. At the same time the pulses in 3 4 induce back on 7 8 and therefore increase the effect on the grid circuit, so that the amplifying effect is built up. There is a danger that the grid potential pulses might be built up so that the plate current goes beyond the straight portion of the curve, but it may be noted that the grid circuit current in 7 8 and the artificial line current in 5 6 are demagnetising ones, hence, by proper design of the coils and by adjustments of grid potential and artificial line, it is possible

to avoid distortion. It is seen that when the valve is switched off communication continues on the line in the ordinary way.

The method can be employed where a phantom line is superimposed on two main or physical lines; the connections would

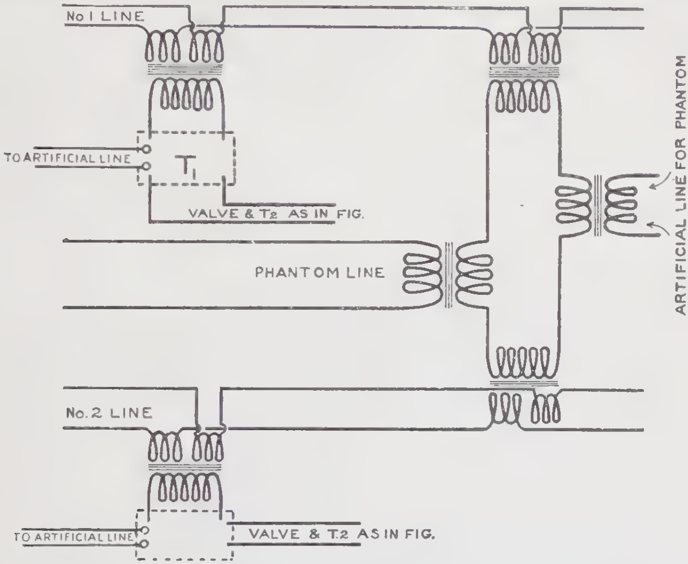


FIG. 240.

then be as shown in Fig. 240; if necessary a valve amplifier can be installed on the phantom line.

Low Frequency Pulses on Valve Generated Oscillations.—In

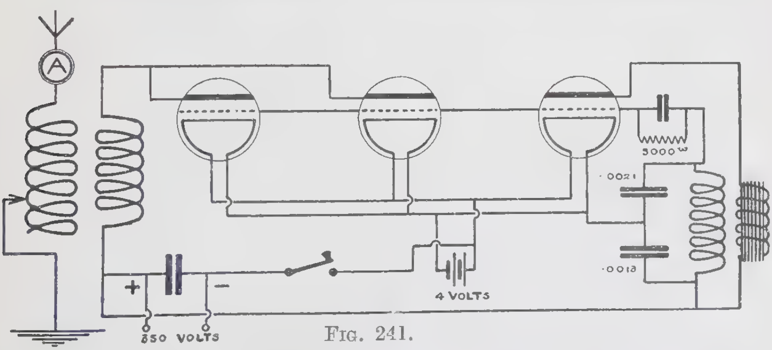


FIG. 241.

Chap. XIV. reference has been made to the fact that undamped oscillations may be generated at a transmitter and signals formed

by impressing on these other oscillations, or pulses, at an audible frequency. The method was illustrated in Figs. 157 and 158; it is suitable for small sets and short ranges, will give very sharp tuning effects, and can be received on a simple circuit.

The method is illustrated again in Fig. 241; here the oscillating plate circuit of two valves in parallel is coupled to an aerial circuit. Oscillations at audible frequency are induced in the circuits of a third valve and these oscillations are impressed on the parallel grids of the two power valves by direct connection to the grid of the modulating valve.

Combined C.W. Transmitter and Receiver.—A Set having the advantages of portability and ease of adjustment was designed by the author with circuits as shown in Fig. 242. The Set is

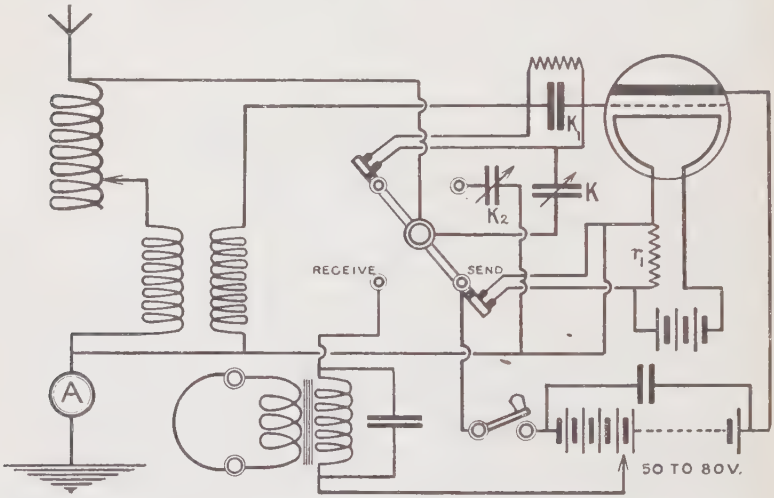


FIG. 242.

contained in a box $10\frac{1}{2}$ ins. $\times$ $10\frac{1}{4}$ ins. $\times$ $8\frac{1}{2}$ ins. and is intended for use with a French receiver type valve.

The coupling coil in the plate circuit has 100 turns of No. 22 S.W.G. silk-covered copper wire, wound on a cylinder $3\frac{5}{8}$ ins. diameter and $3\frac{7}{8}$ ins. long, while the tuning coil has 140 turns of similar wire on a cylinder 5 ins. long and $2\frac{7}{8}$ ins. diameter. There are 19 tappings on this coil to a multiple contact switch.

The grid reaction coil consists of 110 turns of No. 28 wire, or of 100 turns of No. 30 wire, wound on a ball $3\frac{1}{8}$ ins. diameter, mounted

inside the plate coil and capable of rotation through 180° so as to vary the coupling. These dimensions were chosen so that the Set would have a range of wave lengths from 1200 to 1800 metres on a short aerial about 6 yards long and 4 feet high. A small variable condenser with capacity up to 0·0001 mfd., shown at K, is connected across the plate and grid circuits; it adds to the coupling of these circuits and at the same time provides a fine adjustment of tuning. The Set is provided with a change-over switch for Send and Receive, the arm of the switch carrying at each end an insulated stud. When the switch is placed at Send the plate is in series with a 400-volt battery and key, the filament resistance r_1 is short-circuited by one insulated stud on the switch arm so that the filament is heated by the full 6 volts of the battery; the other insulated stud short-circuits a 0·0003 mfd. condenser K_1, with a 3 megohm leak, in the grid circuit. When the switch is at Receive the plate circuit has 50 to 80 volts in series with a telephone transformer, which has the usual shunt condenser and telephone receivers. Also the filament rheostat and leaky grid condenser are brought into action, so that the filament has now only 4 volts across it and the grid condenser makes the valve rectify as well as heterodyne. Instead of the aerial ammeter a small electric lamp may be used to light up when current is oscillating in the aerial circuit, or the lamp may be inserted if the ammeter gets damaged.

Some Sets were made up which had two valves in parallel for transmission; for this purpose the plate and grid terminals of the two valve sockets were respectively connected in parallel, and a spare contact on the change-over switch was utilised to switch the lighting battery on to the filament of the second valve in parallel with the first. This arrangement proved useful either to increase the aerial current or to take undue energy strain off one valve when transmitting. To tune the Set a heterodyning wavemeter is placed near it and adjusted to the correct wave length, the switch is then put to Send, and the inductive coupling between the plate and grid coils adjusted so that maximum current is shown on the aerial ammeter when the key is pressed. The coupling condenser K is set at zero.

The key is then intermittently pressed while the multiple switch on the plate circuit coil is passed from stud to stud. When on the correct stud the beat note will be heard in the wavemeter telephones; the variable condenser is now adjusted until correct tuning gives the silent point in the wavemeter telephones.

When switched over to Receive the valve capacity is slightly

less than before so that the wave length of the Set falls off a little. This can be obviated by slightly increasing the value

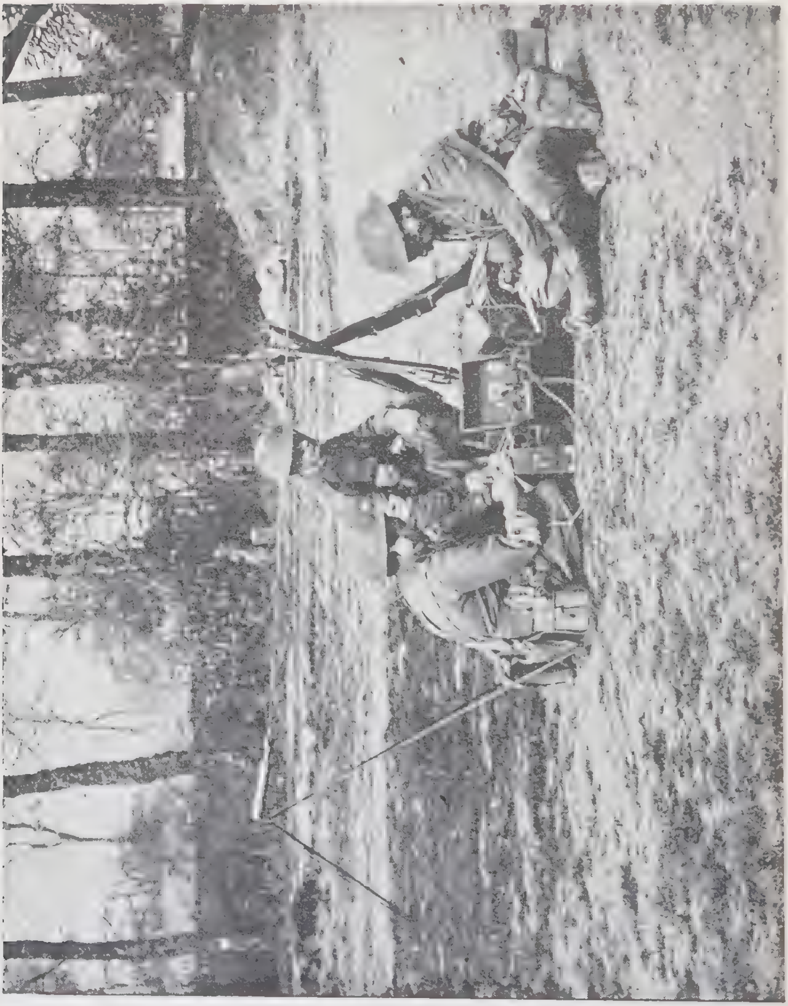


Fig. 242A.

of K, or better still by using the spare contact on the switch to put a small variable condenser K_3 in parallel with the plate coils. This condenser is then adjusted so that when listening

in the telephone receivers on the Set the note heterodyned by the wavemeter is heard.

With receiver type valves two of these Sets will give good signals over a range of 5 miles using aerials 30 feet long, including lead in, and 8 feet high. They will give proportionaly longer ranges on higher aerials or when fitted with amplifiers. If the H.T. battery is in poor condition it should be shunted by a condenser of 0·002 mfd.; the Set would also be improved by having a condenser in series with the aerial. Fig. 242A shows the set in use on an aerial 4 feet high.

Different Circuits Compared for Short Aerial Transmission.—A short aerial implies a small aerial capacity and it may be of interest to compare different methods of connecting up a transmitting valve circuit to such an aerial.

The usual method adopted would be that shown in Fig. 243 (*a*)

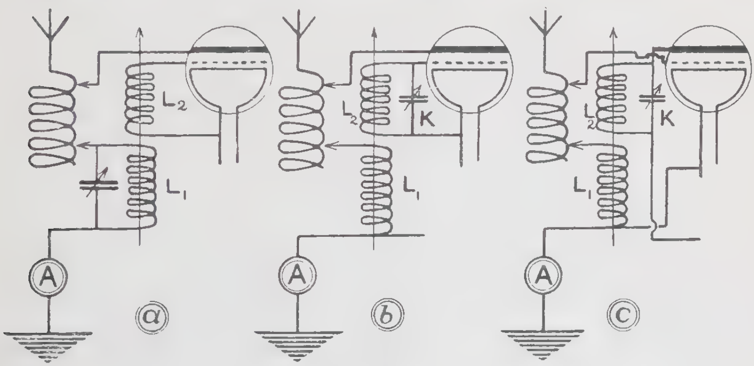


FIG. 243.

omitting the usual connections of battery and key. It is assumed that L_1 is greater than L_2. If the tuning condenser is put in the grid circuit instead of in the plate circuit, and is not of too high a value under these conditions as shown in Fig. 243 (*b*), a good oscillating current will be obtained in the aerial but the plate circuit current will be higher than before in effective value. This connection will give good signals as a receiver.

If the grid circuit is connected across the aerial circuit as shown in Fig. 243 (*c*), while the plate circuit is made up of the smaller inductance L_2 and the tuning condenser, the aerial current will be comparatively small. This will act as a good receiving circuit.

Signalling on very Short Waves.—When Hertz proved the

correctness of Clerk Maxwell's theories by his epoch-making experiment in 1886–87, he was working with very short waves acting on a resonating gap, or receiver, across the length of his laboratory. By the use of parabolic reflectors and wire screens he proved that these waves could be reflected, refracted, and polarised, and had all the characteristics of the very much shorter waves known as waves of light. Marconi's original experiments up to 1896 were carried out on waves of similar length; but the subsequent rapid developments made by him were based on an increase of the height or length of the aerials, and an increase of the wave length.

Early in 1916, during the war, Signor Marconi initiated the idea of again using very short waves, with a reflector or reflectors to give directional effects, and carried out experiments on these lines in Italy. These experiments have since been developed by C. S. Franklin for the Marconi Co. and the results to date are full of promise. They have been described by Franklin in a paper read before the Institution of Electrical Engineers in April, 1922. The preliminary experiments were carried out on wave lengths of 2 or 3 metres using a spark transmitter having a spark gap in compressed air. The reflector employed at the transmitter consisted of a number of parallel wires tuned to the wave length used, and arranged on a cylindrical parabolic curve with the aerial in the focal line; these reflectors could be revolved so that the effects on the distance receiver could be studied. Experimental results, corroborating the previous calculations, show that the waves leave the reflector approximately as plane waves of uniform intensity, having a width equal to the aperture of the reflector. A 3-metre wave used in conjunction with a reflector whose aperture was 2 wave lengths and height 1·5 wave lengths was easily received over a range of 20 miles, using a receiver without a reflector.

In 1919 a valve transmitter for radio-telephony was employed on a 15-metre wave length and clear speech was received from Carnarvon at Kingstown in Ireland, a range of 75 miles. Since then clear and strong speech was established over land between Hendon and Birmingham (a range of 97 miles), using reflectors at both transmitter and receiver, the power employed in the transmitter being about 700 watts, of which about 300 watts was radiated, whilst the aerial was a little longer than half a wave length and the reflector aperture about twice the wave length. Besides the directional effect, and economy of energy by radiating it in one direction only, the great advantage of this system is that interference from atmospherics is practically non-existent; other

advantages are that with a C.W. system reception can take place on the transmitting aerial whilst the transmission is going on, thus simplifying duplex working, and that for radio-telephony no distortion of speech occurs such as is prevalent with non-directional transmission. Signor Marconi has now initiated experiments with revolving transmitters and reflectors, and using only short waves, *i.e.* 4 metres, to evolve a wireless lighthouse. His work in this direction was described by him before the Institute of Radio Engineers, and published in the Proceedings of the Institute, August, 1922. Franklin's experiments go to show that the energy received when reflectors are used at both ends is about 200 times that received when no reflectors are employed, and subsequent research leads in the direction of elaborating the design of the reflectors. The use of suitable generating valves in parallel will increase the amount of power which can be employed in this short wave transmission, and there appears to be no doubt that it will prove a valuable development in radio-signalling, especially for military and naval purposes.

Generating very Short Wave Lengths.—One method of setting up very short waves is shown in Fig. 244; the oscillating plate circuit has an inductance which is only that of the connecting wires in the circuit and therefore can be made very small. Its capacity is that of the valve, between the plate and the grid, in series with a very small condenser K, and with a condenser across the plate battery. Thus the capacity and inductance effects can be made very small and it is possible to set up waves of only 2 or 3 metres length. The coils L_1 and L_2 have adjustable contacts and are intended to give the grid potential a proper value as regards both amplitude and phase. The condenser K couples the plate and grid circuits to sustain the oscillations; its value need not be greater than about 0·000003 mfd.

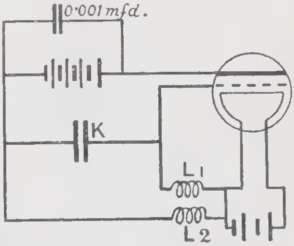


FIG. 244.

A method used by W. G. White is shown in Fig. 245; the inductances in the plate and grid circuits are those of the connecting wires AB and CD respectively and can be made very small. The condensers K_1 and K_2 act in series as a coupling effect; they can be of very small value. The wire W which bridges w_1 and w_2 should be adjusted so that the length of the loop thus formed

is an exact multiple of the wave length of the valve circuit ; this loop is then a coupled circuit in which oscillations of the valve wave length are induced. The coils shown in the battery leads are high frequency chokes. With either of the arrangements shown above it is possible to generate oscillating currents of good amplitude, and the short waves set up by them can be received on a simple Hertz resonator fitted with a vacuum tube or thermo-galvanometer.

Tuned Telephony.—During the summer of 1916 the author carried out some experiments with tuned telephony on a single wire earth return circuit. The instruments used were the portable C.W. Sets shown in Fig. 242. The switch was set in the Receiving position and a Brown telephone earpiece was connected across the series grid condenser instead of the usual high resistance leak ; this telephone receiver was used as a microphone without a battery. The valve filament had about 4 volts applied to it and

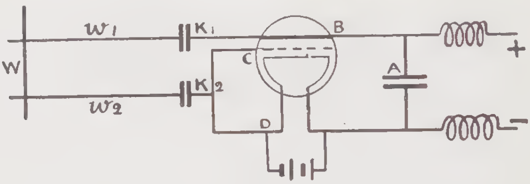


FIG. 245.

an 80-volt battery was used in the plate circuit, which included a telephone transformer and telephone receivers connected up in the usual manner.

With several Sets on a single wire connecting the aerial terminals, the earth terminals being earthed, it was found possible to carry on two or more simultaneous conversations by tuning the pairs of sets to different wave lengths. The tuning was sharp and the speech was very distinct, even when the line wire included a resistance of 700 ohms. One disadvantage of this single arrangement was that the local speech was heard in the local receivers, but this difficulty can be easily surmounted. The experiments were not elaborated at the time because there did not seem to be any possibility that this method of communication had any field service application.

However, these experiments demonstrated that it was quite possible to have several simultaneous conversations on a single wire, and if the valve oscillators had distinct wave lengths these conversations would be secret, each from the others.

Provided that a suitable calling up device can be invented this possibility of tuned telephony would appear to have considerable commercial advantages in the saving of cable and the secrecy attainable.

Testing the Transformers in Amplifiers.—If an amplifier becomes faulty, with a dead effect and no susceptibility for oscillating, it is likely that there is a disconnection in one of the intervalve transformers. The primaries are connected from grid to filament and the secondaries from plate to filament of the succeeding valve. To test the transformers for disconnection without opening up the apparatus the filaments are lighted in the usual manner, H.T. battery connected up, and rheostats or potentiometers adjusted as in normal working. Listening in a pair of telephone receivers the leads from the latter are touched to each grid socket and filament terminal, or to each plate socket and filament terminal as the case may be. Clicks will be heard in the receivers if the transformer windings are not disconnected or broken.

A very useful little testing Set is made by connecting an earpiece of a sensitive telephone receiver in series with a small 4-volt dry battery. When transformer windings have to be tested leads from the receiver and battery are put in contact with the terminals of the windings. When there is no disconnection a click will be heard in the telephone receivers.

Disconnections in the transformer are generally found at the terminals of the winding where the fine wire of the coil is soldered on to a terminal eye ; this joint is often made brittle by the heat of the soldering and is liable to break.

To Measure the Wave Length of Received Undamped Oscillations.—(*a*) If the receiver is fitted with an auto-heterodyning valve, tune the receiver accurately to the incoming wave length so that the silent point is obtained. Now couple a valve oscillating wavemeter loosely to the secondary circuit of the receiver and, whilst listening in the receiver telephones, adjust the wavemeter until the silent point is obtained for it and the receiver valve. The wavemeter will then read the accurate wave length of the incoming oscillations.

(*b*) If the receiver is fitted with a separate heterodyne, the latter is adjusted until the silent point is obtained between it and the incoming oscillations. If the receiver is fitted with a valve detector care must be taken that the latter is not generating oscillations, and the coupling of its circuits should be made as loose as possible. When the silent point is obtained by adjustment of the

separate heterodyne circuit the latter is now set to the wave length of the incoming oscillations; if it is calibrated the wave length can be read direct.

To Measure the Capacity of an Aerial.—A coil whose inductance is at least 20 to 25 times that of the aerial is included in the aerial circuit. An oscillating valve circuit, such as a valve wavemeter fitted for reception, is coupled to the aerial and brought into resonance with the latter. When resonance occurs a slight click will be heard in the wavemeter telephones. The coupling is varied until the click occurs at the same point on the valve circuit condenser whether the resonance point is attained by increasing or decreasing the condenser value. The inductance coil is now disconnected from the aerial and earth and shunted by a variable condenser; this is adjusted to bring the circuit again into resonance with the already adjusted valve circuit, when the reading on the variable condenser will give the capacity of the aerial it has replaced. The method neglects the small inductance effect of the aerial and was first noted by Dr. L. W. Austin.

In a second method the aerial circuit is made up with an inductance coil in series as before; the coil is included in the grid circuit of an auto-heterodyning valve with reaction coupling to the valve plate circuit, which contains a pair of telephones. A generating valve wavemeter is coupled loosely to the aerial circuit and adjusted until the silent point is heard in the telephones. The aerial and earth are now disconnected and replaced by a variable condenser which is adjusted until the silent point is again found. The reading on the variable condenser will then give, fairly accurately, the capacity of the aerial.

Oscillograms of Valve-Generated Oscillations.—Highly interesting experiments have been made by the French Military Wireless Service acting under General Ferrié, with a Kathode Tube Oscillograph, known as the Oscillographe Cathodique Dufour. Preliminary work with this species of apparatus on high frequency oscillations was described in the *Journal of l'Academie des Sciences* in 1914, and further records were made by Lieuts. Beauvais and Ditte during 1917 and 1918 with improved forms of the Oscillographe. The author has not yet received permission to publish any details of the methods adopted with Mons. Dufour's apparatus, but the oscillograms shown in Fig. 246 will serve to demonstrate the valuable aid it has given to the scientific study of valve phenomena.

Fig. 246 (*a*) shows the oscillations of current generated by a valve at a frequency of 69,000 per second: Fig. 246 (*b*) was taken at a frequency of 270,000 and Fig. 246 (*c*) at a frequency of 750,000.

The chief interest of these oscillographs lies in the fact that they demonstrate the remarkable pureness of wave obtainable by means of valves. At each frequency the oscillations of current are seen to be pure sine waves without harmonics: this compares very favourably with the results obtained in arc generated oscillations. The latter are generally more or less rich in harmonics depending on the capacity values with which the arc is shunted: they are also accompanied by periodic trains of damped oscillations, which are caused by the periodic extinction of the arc and depend upon its size. The current oscillations obtainable from a High Frequency Alternator are also certain, for obvious reasons, to be impure and with many harmonics.

Measurement of Plate Circuit Resistance in a Valve and Slope of Curve.—As shown in Chapter II. the current in the plate circuit can be written :—

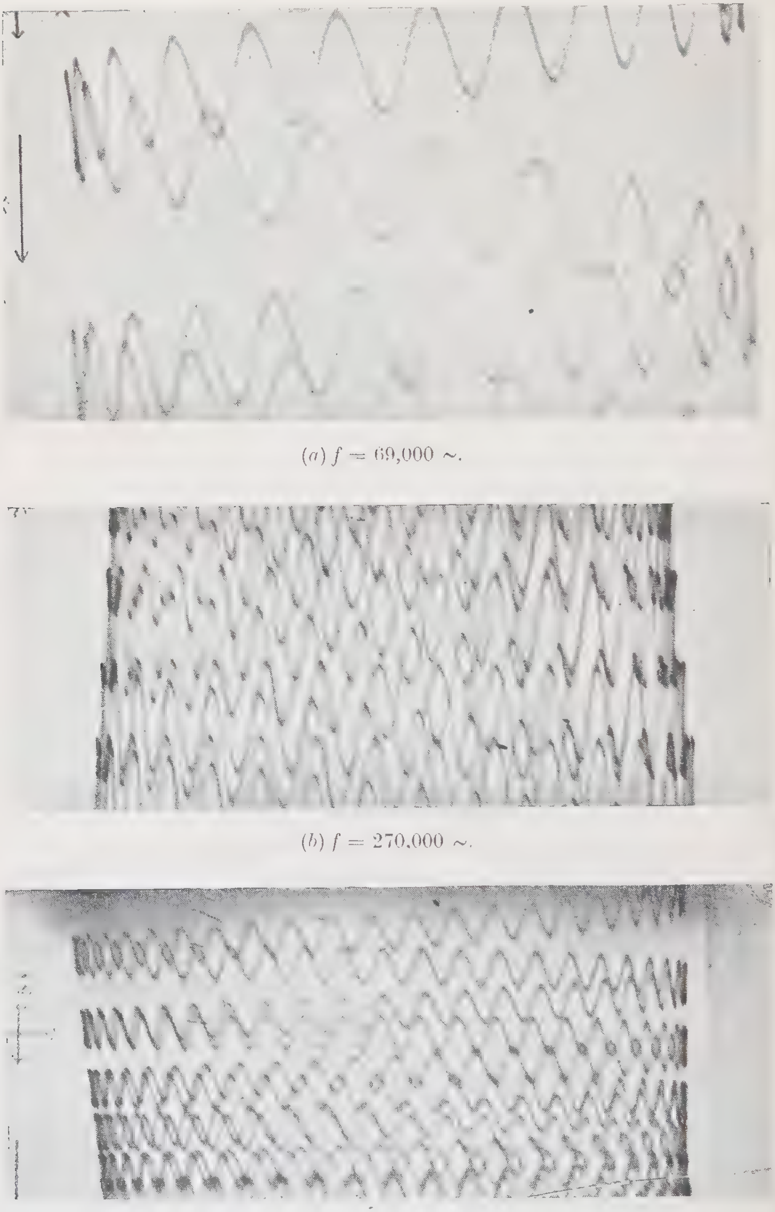
$$C_p = aV_p + bV_g - c$$

The effect of a small increase of plate or of grid potential can be found by taking the differential of the current with respect to these potentials.

Now $\frac{dC_p}{dV_p} = a$, and $\frac{dC_r}{dV_g} = b$, therefore $\frac{dC_p}{dV_p} \Big/ \frac{dC_p}{dV_g} = \frac{a}{b}$; also the plate circuit resistance, $r_p = \frac{1}{a} = \frac{dV_p}{dC_p}$.

In the *Wireless World* of November, 1918, Mr. E. V. Appleton has given an experimental method of determining $\frac{a}{b}$ and b, so that $\frac{1}{a}$, or r_p, is then easily derived. The apparatus and circuits employed have been called by him a "Slopemeter," since $\frac{dC_p}{dV}$ determines the slope of the plate current–plate potential curve at any point and $\frac{dC_p}{dV_g}\Big/$ the slope of the plate current–grid potential curve.

Slightly modified diagrams of Appleton's circuits are given below in Figs. 247 and 248. Referring to Fig. 247 the plate and grid circuits are completed to the filament through resistances R_1 and R_2, by means of a sliding contact. A battery, B, is connected through a key, K, across R_1 and R_2. The plate current is



(a) $f = 69{,}000 \sim$.

(b) $f = 270{,}000 \sim$.

(c) $f = 750{,}000 \sim$.

FIG. 246.—Valve Current Oscillations.

first read on A with K open ; then K is closed and a current X flows from B through R_1 and R_2. The potential across R_1 is now R_1X and the grid potential is therefore made positive by this amount.

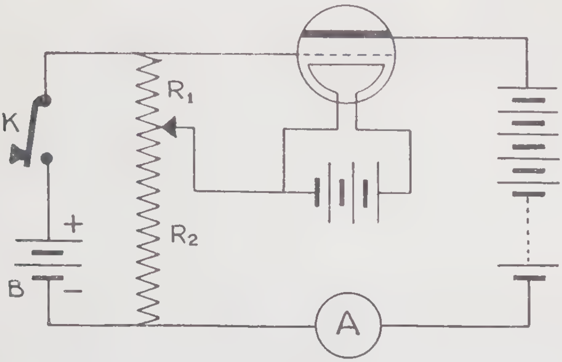


Fig. 247.

The increase of plate current due to this increase of grid potential would be $(b \times R_1X)$, or $R_1X\frac{dC_p}{dV_g}$. However, at the same time the current X flows through R_2 and decreases the plate potential by an

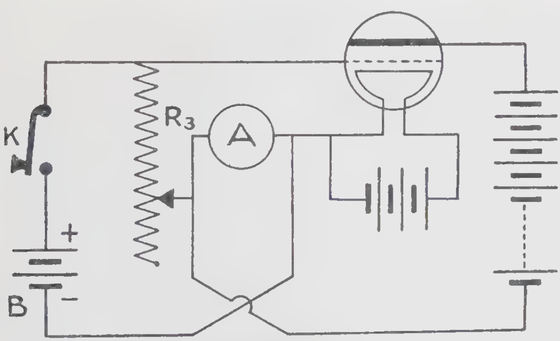


Fig. 248.

amount R_2X ; the decrease of plate current due to this is $a \times R_2X$, or $R_2X\frac{dC_p}{dV_p}/$. By manipulating the slider it is possible to adjust the values of R_1 and R_2 so that the plate current does not change when the key is pressed, in other words the increase due to rise of

grid potential is just counterbalanced by the decrease due to fall of plate potential. Thus, when the balance is obtained,

$$R_1 X \frac{dC_p}{dV_g} = R_2 X \frac{dC_p}{dV_p}$$

$$\therefore \frac{dC_p}{dV_p} \Big/ \frac{dC_p}{dV_g} = \frac{a}{b} = \frac{R_1}{R_2}$$

The circuit is now made up as in Fig. 248; and with K open the plate current is read on A. If the key is now closed a current, Y, flows through R_3 and A from the battery B. If r is the resistance of A this current causes a drop of potential across R_3 and A whose value is $(R_3 + r)Y$; in other words the potential of the grid with respect to the filament is raised by this amount. Therefore the plate current is increased by an amount :—$b(R_3 + r)Y$, or $\frac{dC_p}{dV_g} \times (R_3 + r)Y$. Now the battery current, Y, flows through A in the opposite direction to the plate current, and it is possible to adjust the value of R_3 so that the reading on A is the same whether the key is open or closed. Obviously then—

$$Y = \frac{dC_p}{dV_g}(R_3 + r)Y$$

or
$$\frac{dC_p}{dV_g} = \frac{1}{R_3 + r} = b.$$

Thus
$$\frac{a}{b} = \frac{R_1}{R_2} \text{ and } b = \frac{1}{R_3 + r},$$

$$\therefore r_p = \frac{1}{a} = \frac{dV_p}{dC_p} = \frac{R_2}{R_1(R_3 + r)}$$

The solution of Fig. 248 described above does not take into account the flow of grid current through A when the grid is made positive; the grid current will, however, be very small compared to the plate current.

From the solution for r_p it is evident that R_2 must be chosen of a very high value compared to R_1 and R_3.

The ammeter A should preferably be a very sensitive galvanometer or milliammeter, shunted if necessary.

High-Speed Working.—The development of radio telegraphy as a competitor to cable working over long distances depends

largely on the progress which can be made in high-speed reception. The capital outlay on a long-distance radio equipment is becoming

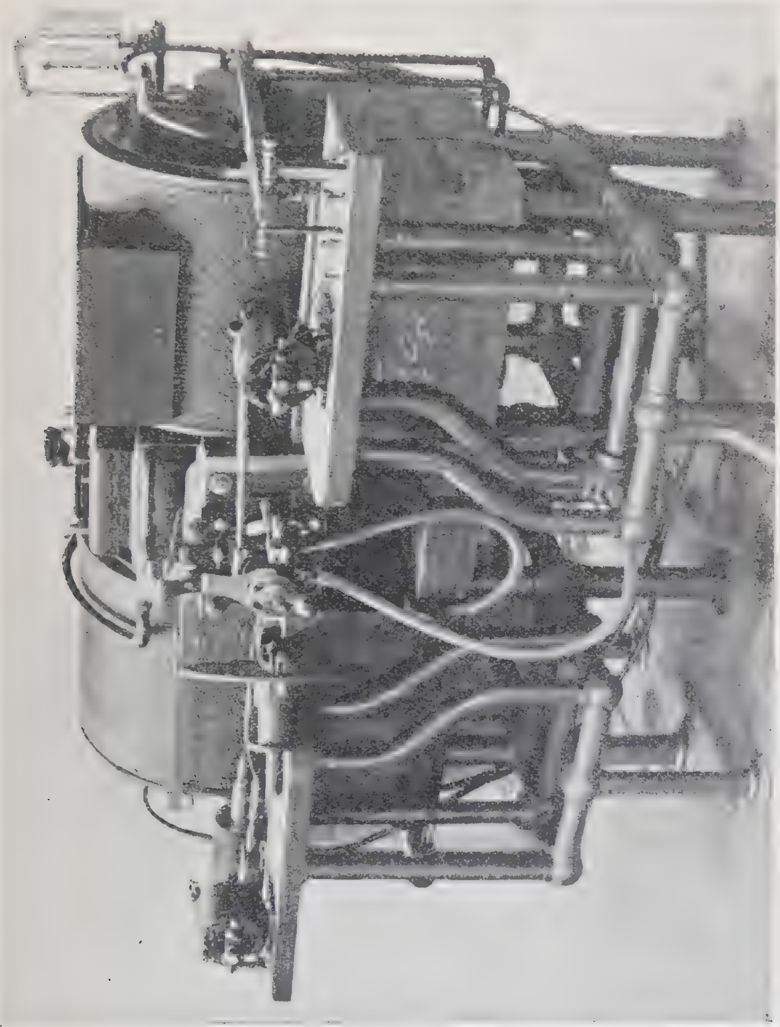


FIG. 249.—100 K.W. Arc Generator in San Francisco Station.
By permission of the Federal Telegraph Co., U.S.A.

increasingly expensive, since the only remedy for atmospheric interference at the present time appears to be an increase in trans-

mitting power: it is therefore important that the plant should be kept working as continuously as possible, and should handle a maximum of traffic in a given time. Naturally the greatest amount of traffic is handed in during the ordinary business hours of the daytime at the transmitting end, and in order to encourage traffic during night hours and week-ends some Companies have arranged cheaper rates for messages which can be handled during these hours. Thus many of the Linen Companies in Belfast can radio to the United States by night messages at cheaper rates than the ordinary cable rates.

At the same time it is most desirable that the speed of signalling should be as high as possible, but the limitations in this respect are mostly at the receiving end. Automatic transmission at 100 words per minute is now provided in many of the high power stations, where the only difficulty encountered is that of keeping a perfectly constant wave length: this difficulty does not arise to the same extent with Valve transmitters as with Arcs and High Frequency Generators. As regards high-speed reception one of the earliest methods developed was that of using a Dictaphone in which the message is taken on a wax cylindrical record run at suitable speed, say 400 revolutions per minute. This record is then put on a slower running phonograph and taken down by an operator; it is then shaved over and made ready for use again. In the United States the Poulsen telegraphone is employed in a similar manner. The disadvantages of such a system are obvious; there must be at least two machines installed for recording long messages, four or five transcribing the messages, and one or two for shaving the records; there is delay between the reception of a message and its preparation for the recipient; there is no permanent record of the reception work; the staff required to receive, transcribe and shave the records is excessive: finally, the system does not lend itself to duplex working, since faulty transmission cannot be checked immediately and much valuable time, energy, and power may be wasted.

Another method which has been employed is that of taking a photographic record by means of an Einthoven String Galvanometer in Europe, or by the Hoxie Recorder of the General Electric Company in America. This method has none of the disadvantages mentioned above in connection with the Dictaphone receiver, but the instruments are expensive, and they are of delicate construction so that an expert staff is required to adjust them. Thus neither of these instruments is suitable for installing in remote or rural

stations, where the operators would not be sufficiently expert to effect repairs or instal spare parts.

Yet another system which has been employed is the Creed Recorder, but this is also an expensive and complicated apparatus which requires the attention of a skilled staff. Finally, we are left to consider the use of Morse Inkers and Siphon Recorders. A Morse Inker requires about 50 milliamperes to work it; thus it must be employed in conjunction with a comparatively powerful low frequency amplifying combination, or with telegraphic relays, or both. Its use is really ruled out by the fact that atmospherics play havoc with its record.

Ordinary types of Siphon Recorders will work on less than a milliampere of current and can therefore be employed behind a multivalve low frequency amplifier. Owing to the mechanical inertia of its moving part a Siphon Recorder of ordinary design cannot be employed on speeds above 50 words per minute; it is not of rugged construction, and therefore not suitable for installation in remote stations. An improved type of Siphon Recorder has been developed by Messrs. E. Blakeney and S. C. Miller, members of the staff of the Radio Corporation of America; this is described in a paper read by Julius Weinberger before the Institute of Radio Engineers. It has much of the ruggedness of construction of a moving coil galvanometer, and consists of a small coil of fine insulated wire, suspended horizontally by four radial threads in the field of a strong electro magnet. To the coil is attached a light lever arm at the end of which a small tubular metal inker is mounted, with arrangements to regulate the ink supply to it automatically from the container. The signal currents passing through the small coil cause it to rise in the magnetic field, and there is an arrangement for damping the motion, so that the tops of the dashes and dots are recorded clear and square at the ends. This recorder has worked satisfactorily on speeds up to 100 words per minute, giving a record which is much clearer than that provided by other methods. It is shunted by a condenser, and used behind a low frequency amplifier of three to six valves depending on the strength of the signals.

The recorder requires from two to four milliamperes of direct current to work efficiently, and the necessary step-up of telephone current is carried out by a special valve amplifier, consisting of three of the Radio Corporations five watt valves, known as the U.V. 202 type. These are employed with 7·5 volts on the filament, 2·35 amperes filament current, and 220 volts for the plate circuits.

The first two valves are employed in cascade, as amplifiers, the third valve being used as a rectifier. All are interconnected in the ordinary way by iron core transformers, but the circuit of the first valve may be tuned to the audio frequency by connecting a variable condenser of 0·001 mfd. capacity across the secondary of the step-up transformer between the radio circuit and this valve. A capacity of 1 mfd. is shunted across the recording instrument.

Duplex Working and Future Development. The future development of radio signalling for commercial purposes will demand an extension of the system now adopted by the large Radio Corporations, that is to say all reception and transmission will be operated from a central building connected by wires to the transmitting and receiving stations. In the central office the transmitting and receiving operators may work at the same table, so that faulty transmission from the distant station, detected by the receiving operator, can be immediately signalled by the transmitting operator, with a consequent saving of time, energy, and material.

The receiving operator may probably have in his charge only the recording apparatus or telephony receivers; between him and the radio receiving outfit there will be a station containing the necessary amplifiers and relays for the audio frequency pulses. Similarly the transmitting operator will have in front of him only the transmitting key or microphone apparatus; between him and the transmitter there will be a station containing the line relays.

The radio transmitting and receiving stations will be from 15 to 20 miles apart with L type directional aerials, and each system may be made more selective by transmitting a super-audio frequency modulation superimposed on the continuous waves, so that a double tuning will be required at the receiver.

A great development of co-operation between wired signalling and radio signalling should take place in the near future; thus it should soon be possible for any person to sit at his office or home telephone and carry on a conversation with a passenger on a ship at sea, or in some distant place, through combination of wired and radio telephony.

In this connection an interesting demonstration was recently made in America when telephony was established between Catalina Island in the Pacific and Havana in the Atlantic. The speech was sent from Catalina across the Pacific by radio, the receiver of which was connected to the telephone lines so that the message was thus carried across the United States and thence by submarine

cable from Key West to Havana. There is no reason why the section from Key West to Havana should not have been done by radio, had the necessary apparatus been available.

Development since the termination of the World War has not been as rapid as might have been expected, but this is no doubt partly due to the condition of the world's finances, and partly due to the confusion which existed in radio patents. For these reasons, combined with lack of State enterprise, our progress in Great Britain and Europe is much behind that in the United States, but there is no doubt that the stage is set for a rapid development and much important scientific advance is now waiting for its commercial application. In the author's opinion the two outstanding problems for research work are those connected with the elimination of atmospherics, and with the invention of a cheap and rugged system of high-speed reception.

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